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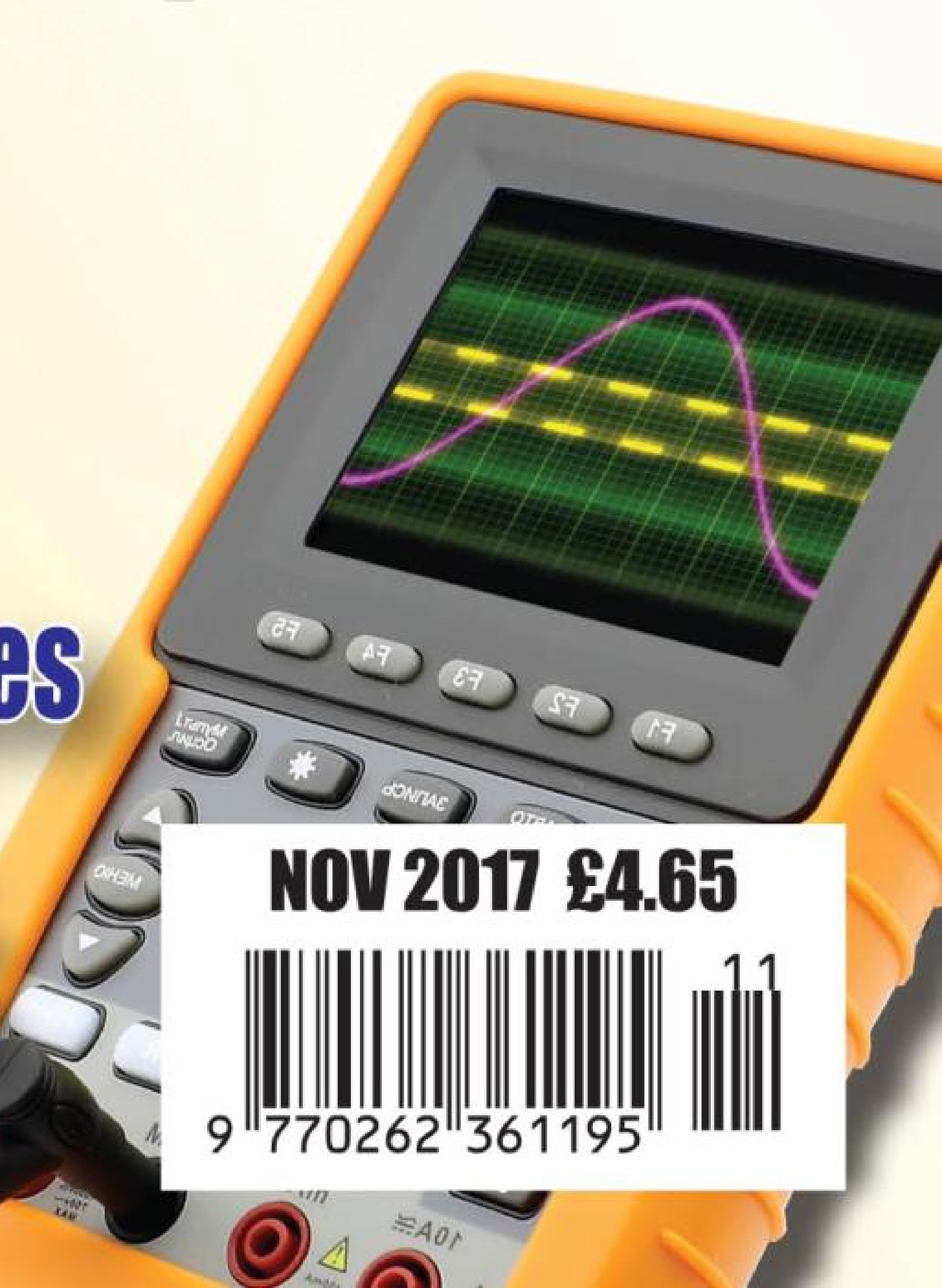

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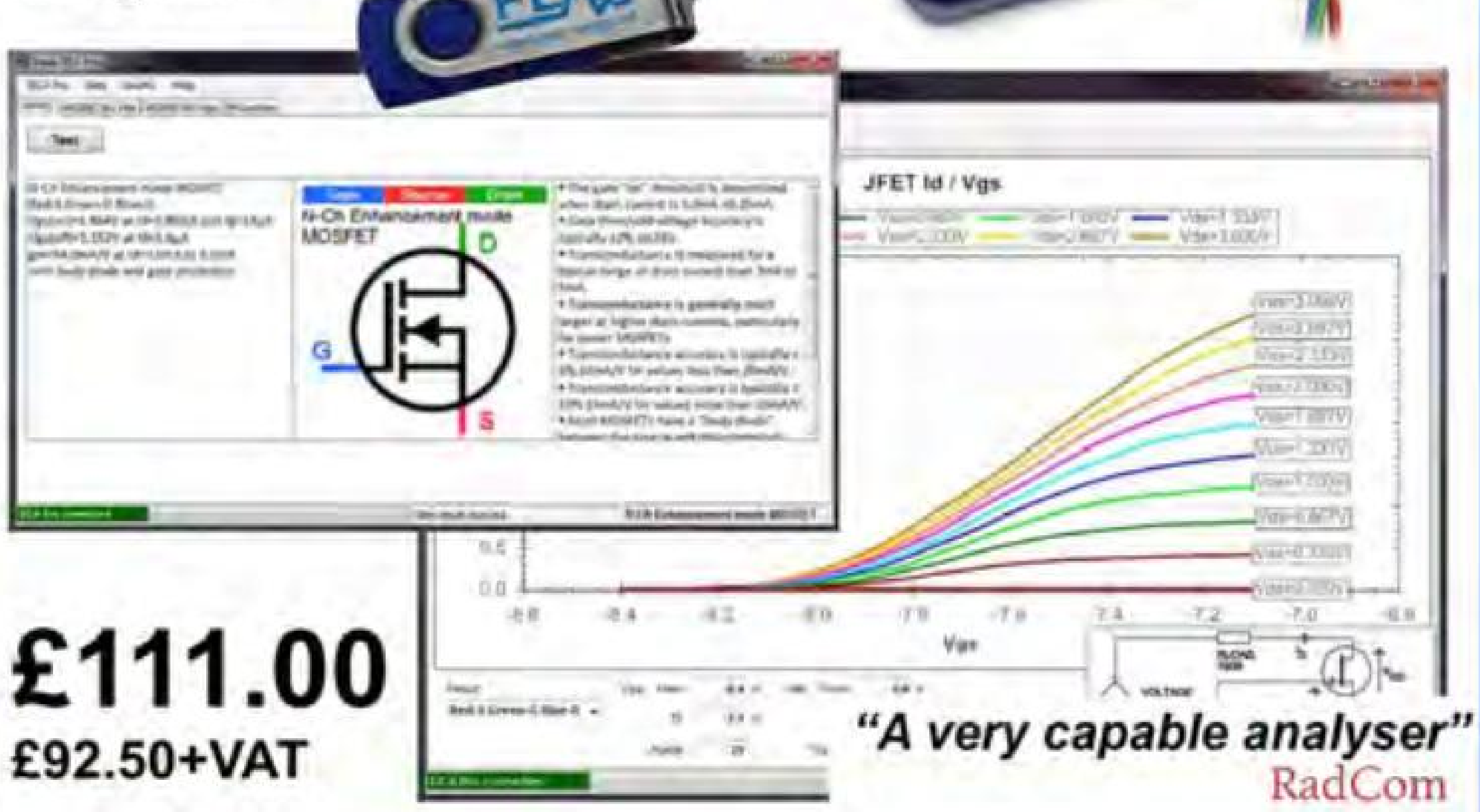
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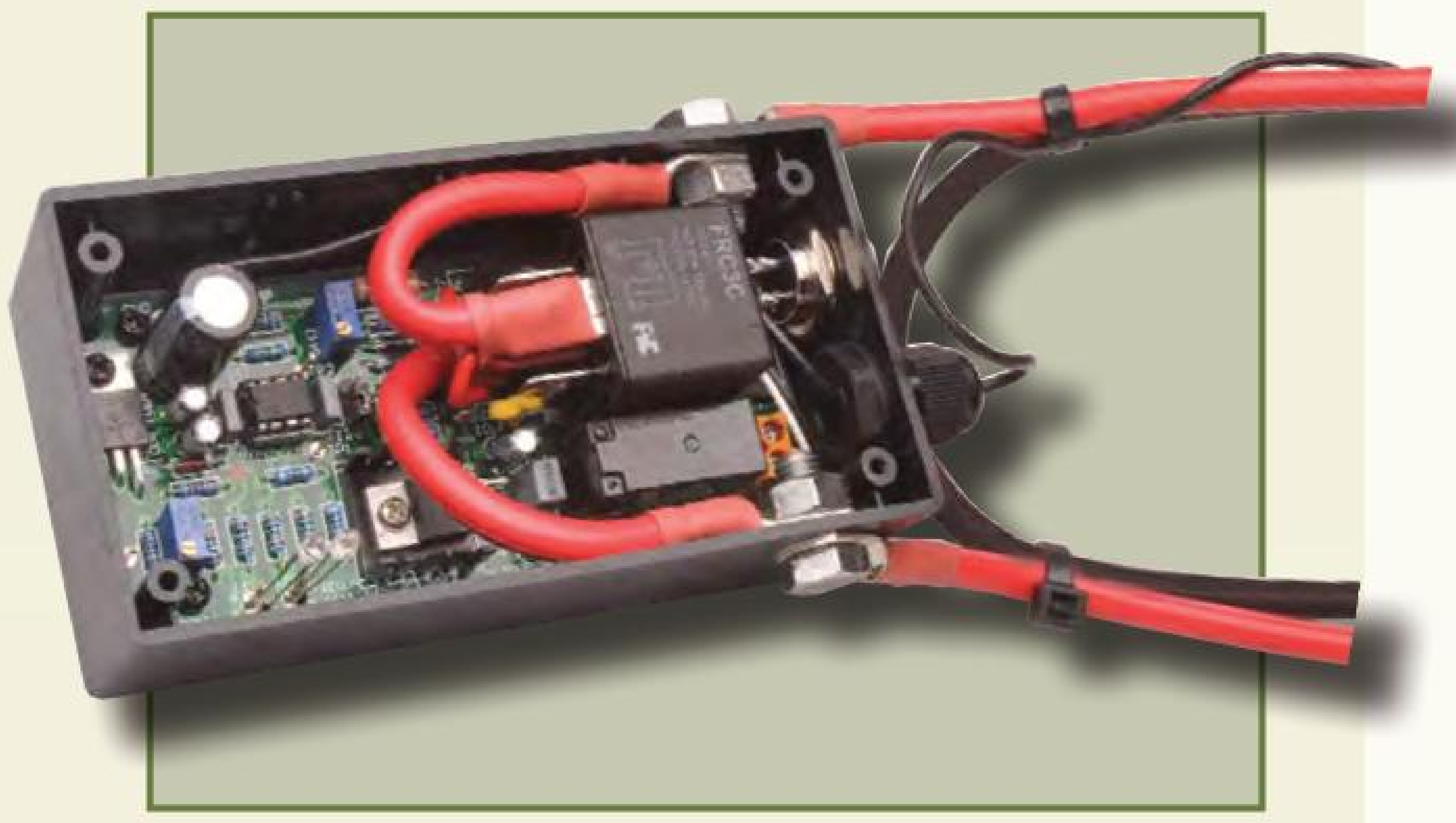

LED FLASHER
LED1
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D2
1nF
1N4148
1µF
D1

IN
OUT
L
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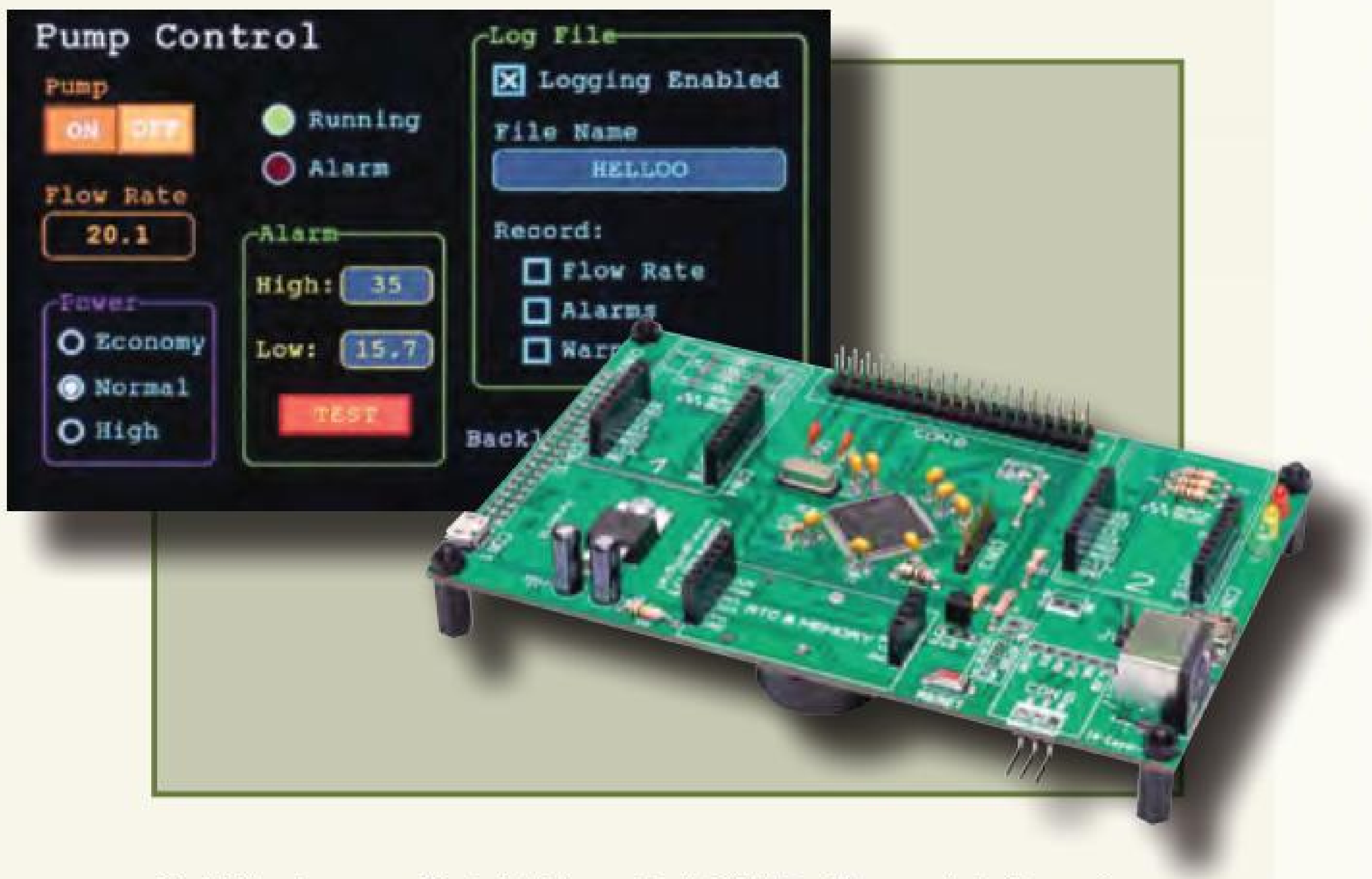
PHONO INPUT CONVERTER



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Our December 2017 issue will be published on Thursday 2 November 2017, see page 72 for details.

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Assembled ZIF: AS3123ZIF- ~~£48.96~~ £37.96

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Fast programming. Wide range of PICs supported (see website for details). Free Windows software & ICSP header cable. USB or Serial connection. ZIF Socket, leads, PSU not included.
Kit Order Code: 3149EKT - ~~£49.96~~ £29.95
Assembled Order Code: AS3149E - £44.95
Assembled with ZIF socket Order Code: AS3149EZIF - ~~£74.96~~ £49.95

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USB Experiment Interface Board

Updated Version! 5 digital inputs, 8 digital outputs plus two analogue inputs and two analogue outputs. 8 bit resolution. DLL.
Kit Order Code: K8055N - ~~£39.95~~ £22.74
Assembled Order Code: VM110N - £39.95

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State-of-the-art high security. Momentary or latching relay outputs rated to switch up to 240Vac @ 12 Amps. Range up to 40m. 15 Tx's can be learnt by one Rx. Kit includes one Tx (more available separately). 9-15Vdc.
*Kit Order Code: 8157KT - **£44.95***
*Assembled Order Code: AS8157 - **£49.96***

Computer Temperature Data Logger

Serial port 4-ch temperature logger. °C/°F. Continuously log up to 4 sensors located 200m+ from board. Choice of free software applications downloads for storing/using data. PCB just 45x45mm. Powered by PC. Includes one DS18S20 sensor.
Kit Order Code: 3145KT - ~~£19.95~~ £16.97
Assembled Order Code: AS3145 - £22.97
*Additional DS18S20 Sensors - **£4.96 each***

8-Channel Ethernet Relay Card Module

Connect to your router with standard network cable. Operate the 8 relays or check the status of input from anywhere in world. Use almost any internet browser, even mobile devices. Email status reports, programmable timers... Test software & DLL online.
Assembled Order Code: VM201 - £134.40

Computer Controlled / Standalone Unipolar Stepper Motor Driver

Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
*Kit Order Code: 3179KT - **£17.95***
*Assembled Order Code: AS3179 - **£24.95***

Many items are available in kit form (KT suffix) or pre-assembled and ready for use (AS prefix)

Bidirectional DC Motor Speed Controller

Control the speed of most common DC motors (rated up to 32Vdc/5A) in both the forward and reverse directions. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections. PCB: 90x42mm.
*Kit Order Code: 3166KT - **£19.95***
*Assembled Order Code: AS3166 - **£25.95***

8-Ch Serial Port Isolated I/O Relay Module

Computer controlled 8 channel relay board. 5A mains rated relay outputs and 4 opto-isolated digital inputs (for monitoring switch states, etc). Useful in a variety of control and sensing applications. Programmed via serial port (use our free Windows interface, terminal emulator or batch files). Serial cable can be up to 35m long. Includes plastic case 130x100x30mm. Power: 12Vdc/500mA.
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*Assembled Order Code: AS3108 - **£89.95***

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Computer serial port temperature monitor & relay controller. Accepts up to four Dallas DS18S20 / DS18B20 digital thermometer sensors (1 included). Four relay outputs are independent of the sensors giving flexibility to setup the linkage any way you choose. Commands for reading temperature / controlling relays are simple text strings sent using a simple terminal or coms program (e.g. HyperTerminal) or our free Windows application. Supply: 12Vdc.
Kit Order Code: 3190KT - ~~£79.96~~ £49.96
Assembled Order Code: AS3190 - £59.95

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*Kit Order Code: 8191KT - **£29.95***
Assembled Order Code: AS8191 - £29.95

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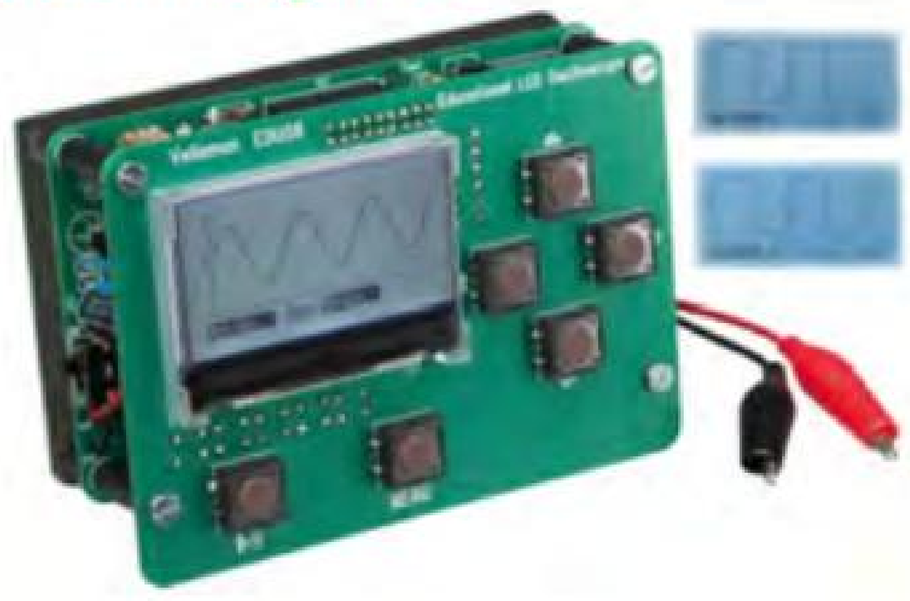
Compact, portable battery powered fully featured two channel oscilloscope. Instead of a built-in screen it uses your tablet (iOS, Android™ or PC (Windows) to display the measurements. Data exchange between the tablet and the oscilloscope is via WLAN. USB lead included.
Code: WFS210 - ***£79.20*** *inc VAT & Free UK Delivery*

LCD Oscilloscope Self-Assembly Kit



Build your own oscilloscope kit with LCD display. Learn how to read signals with this exciting new kit. See the electronic signals you learn about displayed on your own LCD oscilloscope. Despite the low cost, this oscilloscope has many features found on expensive units, like signal markers, frequency, dB, true RMS readouts. 64 x 128 pixel LCD display.
Code: EDU08 - ***£49.99*** *inc VAT & Free UK Delivery*

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Order Code 1199KT - ***£69.95*** *inc VAT & Free UK delivery*

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0Hz to 12MHz digital storage oscilloscope, using a computer and its monitor to display waveforms. All standard oscilloscope functions are available in the free Windows program supplied. Its operation is just like a normal oscilloscope. Connection is through the computer's parallel port, the scope is completely optically isolated from the computer port. Supplied with one insulated probe x1/x10.
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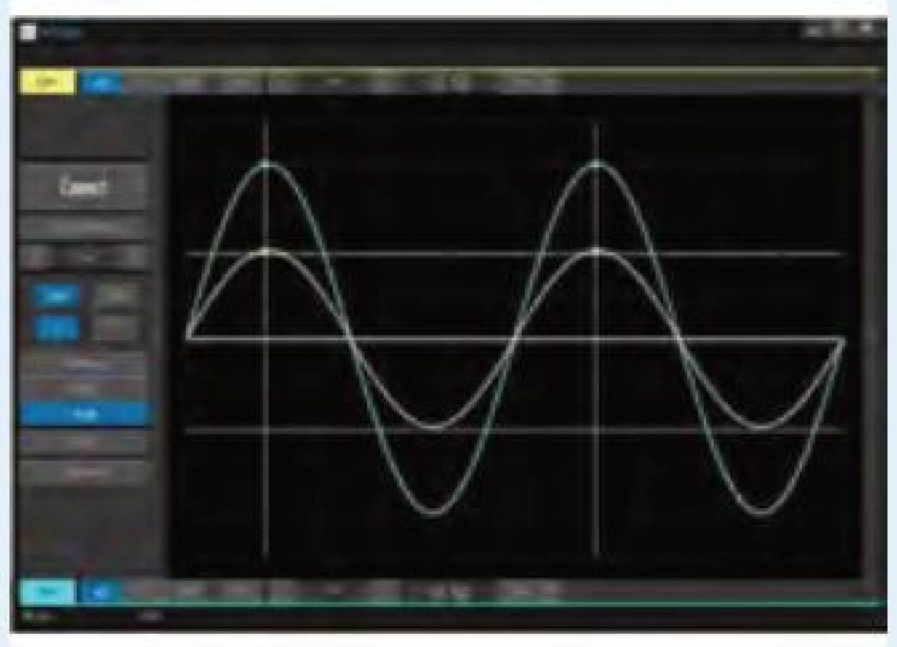
WFS210 2 Channel WLAN Scope



The Velleman WFS210 is the world's first WLAN dual channel digital storage oscilloscope geared towards tablet computers. A compact, portable battery powered fully featured. Instead of a built-in screen it uses your tablet (iOS, Android™ or PC(Windows)) to display the measurements. Data exchange between the tablet and the oscilloscope is via WLAN.

- High sensitivity: up to 0.2mV
- Full auto setup function
- Signal markers / Hold function
- DVM readouts
- Li-ion rechargeable battery included (3.7V 1800mAh)
- Input range: 5mV to 20V/div (12 steps)
- Timebase: 1μs to 1s/div
- Max. 30Vpp input
- Bandwidth: 2 x 10MHz (-3dB at selected ranges)
- Readouts: DC, AC+DC, True RMS, dBm, Vpp, Vmin, Vmax.

Quote: EPEWFS

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HPS140MK2 Oscilloscope

£119.94
Inc Delivery* & VAT

The HPS140MK2 handheld oscilloscope still holds the same power as its predecessor, but in a new and modern design. Although small in size, this oscilloscope packs 40 MS/s in real time and it's sensitivity can go as low as 0.1 mV. It also has a full automatic measuring system but can be operated manually if preferred.

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- 40 Mega samples/sec in real time
- Bandwidth up to 10 MHz
- Full auto range option
- Signal markers for amplitude and time
- Memory hold function
- Direct audio power measurement
- Stylish OLED Display

Quote: EPEHPS2

HPG1 Function Generator

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A complete pocket function generator. Now you can take test signals on the move, 3 waveforms can be selected. Set the output voltage or frequency and select signal waveform using the on the screen menu. A powerful sweep function is also included.

* Frequency range: 1Hz to 1.000.000Hz
* Frequency steps: 1Hz, 10Hz, 100Hz, 1kHz and 10kHz
* Sine, square and triangle wave forms
* Runs on NiMH rechargeable battery pack (includeed)
* BNC Lead and Charger Included.
Quote: EPEHPG

£91.19
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2.4GHz Frequency Counter

0.01Hz to 2.4GHz
8 Digit LED Display
Gate Time: 100ms to 10s
2 Channel Operating mode
Power Supply: 110-220Vac 5W
Quote: EPE24G

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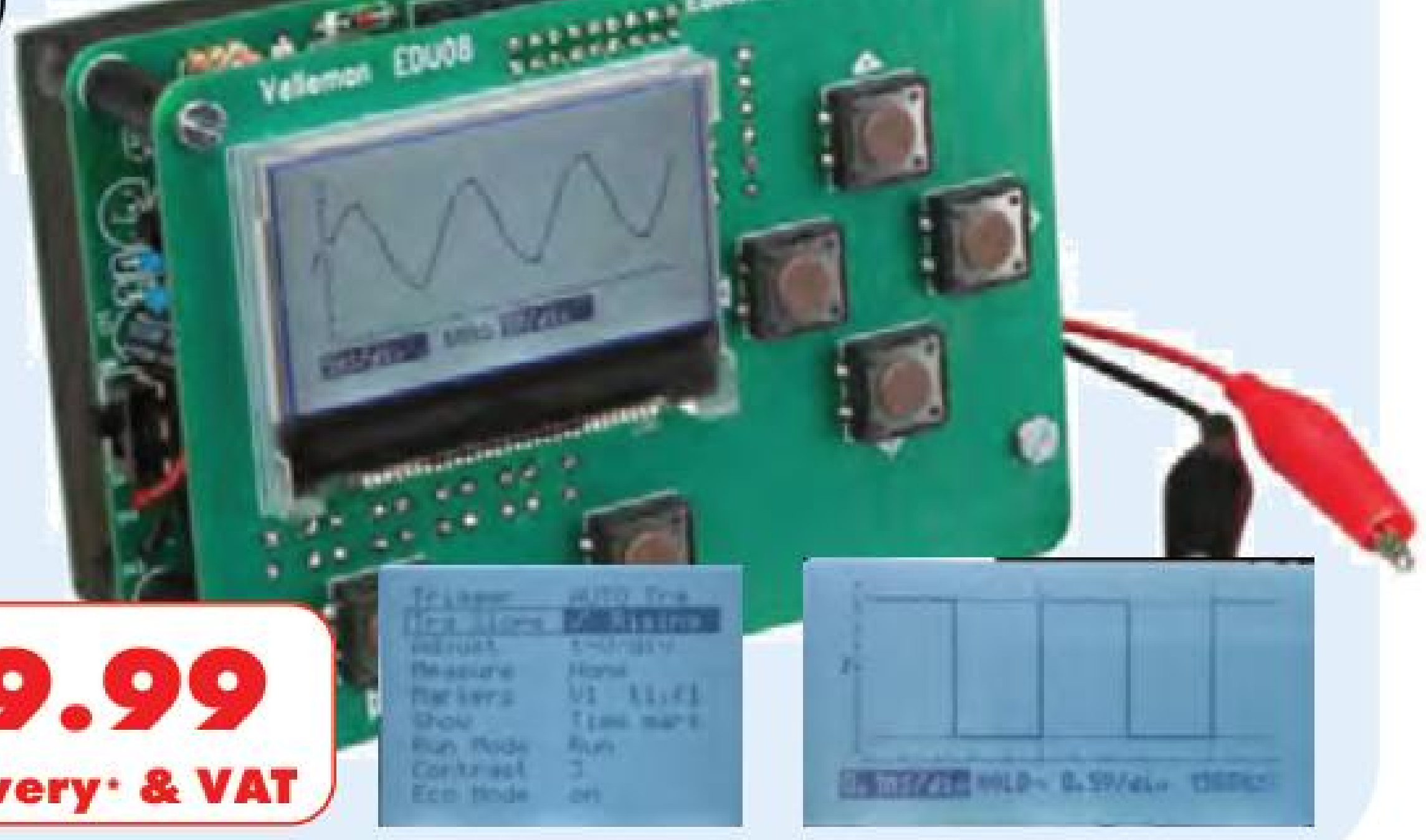

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Charge those batteries!

Electricity is great. Yes, you knew that already; it's hardly news in a magazine devoted to electronics. However, most of us take it for granted until its supply is not so easy to come by, which is definitely an issue if you enjoy touring in a recreational vehicle and your day-to-day home comforts run off large batteries that inevitably need regular charging. This month's *50A Battery Charger Controller* project is a very neat and handy way to combine a 230V portable generator and large 12/24V batteries – strongly recommended.

So, what else do we have for you this month? Mike Tooley's latest *Teach-In* series is now getting nicely into its stride with a great introduction to the wide range of scopes – both new and not-so-new – that hobbyists can use. Mike O'Keeffe looks at Microchip plugins and Ian Bell continues his examination of microcontrollers and temperature measurement. That's a just a small selection of the treats for you in November's edition, and I hope you enjoy reading it as much as we enjoyed putting it together for you.

Electronics matters

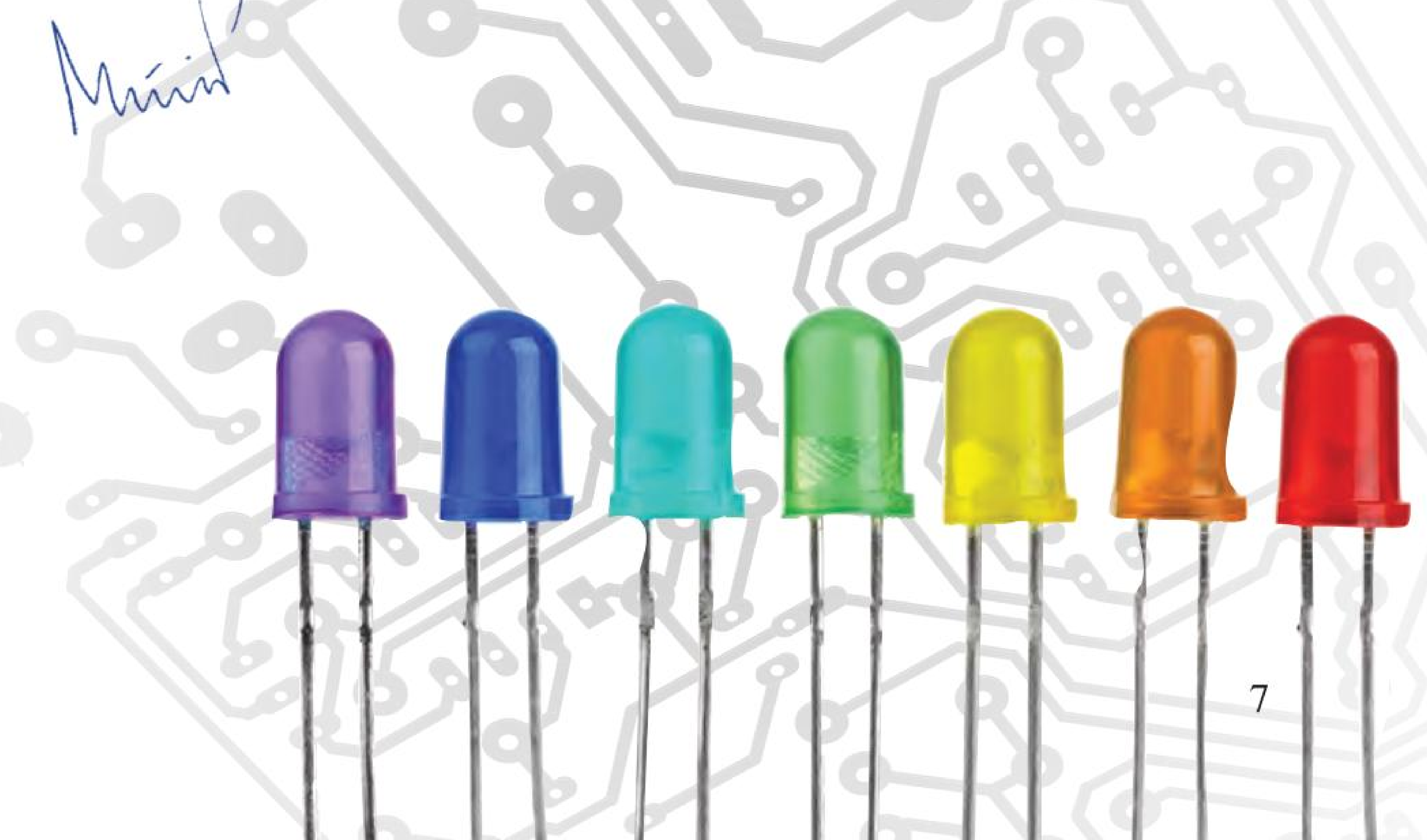
This is not an industrial magazine, although I know many professional engineers do read and enjoy *EPE*, but I do have a brief message for those of you who have sons and daughters reaching the stage where they are starting to think about 'A' level choices, university courses and careers. Despite what some of the less serious sections of the media would have you believe, Britain is still an important industrial nation. We may no longer be top dog, but we are still in the top eight for manufacturing output. If we are to retain or even improve on that position then we need more engineers, technicians, inventors and those with STEM subject (science, technology, engineering and mathematics) backgrounds. The latest government research suggests that the future shortfall in the right kind of highly employable young people will be in the hundreds of thousands. So, if you enjoy electronics and can see its value then I urge you to talk to today's children and explain to them that electronics offers a fascinating, well-paid career and electronics skills are not only in demand, but also are likely to be even more valuable and sought after in the future.

Chat Zone

I would like to echo Alan Winstanley's reminder in this month's *Net Work* that the old *EPE Chat Zone* is being semiretired from October. If you are a regular *Chat Zone* user then please see his full message on page 45.

Subscription information

Before signing off, a note to all our loyal subscribers – if you didn't read it last month, then please read the announcement on page 72 about changes to subscribing to *EPE*. Also, please see page 5 and take advantage of the price freeze!



NEWS

A roundup of the latest Everyday News
from the world of
electronics

Searching for a VR motion sickness cure – report *by Barry Fox*

Is VR (virtual reality), along with AR (augmented reality) and MR (mixed reality) the new 3D – something that works as an event attraction, where people are prepared to wear something over their eyes, but not in the home where most of us don't want to wear anything to watch something?

And just like 3D, VR (along with AR and MR) quite literally makes some people feel sick. The VR industry knows this only too well because companies use the promise of not making people feel ill a USP – a 'unique selling point'. How many other products can you think of that sell with the message, 'ours doesn't make you feel quite so sick as theirs does'?

Patents galore

Recently, I did some research into VR sickness and found that over the last 25 years the US Patent Office has granted over 60 patents which directly refer to 'motion sickness' in the context of VR. The patents often admit that the exact causes are not yet fully understood and new patent applications on cures for the problem are still being filed, which suggests there is not yet any single magic-bullet fix.

Many filings were lodged by small specialist companies and individual inventors, but big name corporates and even the US Army feature among the filings.

The big names include Olympus, with filings dating from 1993, Walt Disney (1994), Raytheon and Hughes (1996), Mitsubishi and Intel (1997), Philips (1998), Eastman Kodak (from 2001 through to 2010), Massachusetts Institute of Technology (2007), Panasonic (2012), Microsoft (2013) and the US Army Research Laboratory (between 1997 and 2013).

Plenty of symptoms…

Kodak's US patent 8594381 helpfully defines motion sickness as 'the general term describing a group of common symptoms such as nausea, vomiting, dizziness, vertigo, disorientation, sweating, fatigue, ataxia, fullness of stomach, pallor'.

VR systems are widely used for applications as diverse as gaming, health and safety training and entertaining EPE *columnist Clive 'Max' Maxfield, a keen exponent of VR (and interesting shirts). However, a persistent problem is users expeiencing motion sickness.*

'Although sea-, car-, and airsickness are the most commonly experienced examples' the patent says, 'these symptoms were discovered in other situations such as watching movies, video, in flight simulators, or in space (and) motion sickness is a significant obstacle for users of immersive and virtual reality systems and head-mounted displays, limiting their widespread adoption despite their advantages in a range of applications in gaming and entertainment, military, education, medical therapy and augmented reality… motion-sickness symptoms are known to occur in users wearing head-mounted displays during head or body motion, as well as when watching content or playing computer games for a relatively prolonged period even without head or body motion.'

Two of Disney's patents (US 6007338 and 5551920) deal with simulators, as do several from the US Army (6050822, 8988524 and 9434309). US patent 5991085, a 1995 filing from i-O Systems of Menlo Park, discusses the use of head-mounted displays 'to provide an image-only or 'immersive' device' and suggests that the wearer be given 'the option of achieving a view of the environment… to avoid a motion-sickness-like feeling.'

US patent 5579026, filed by Olympus Optical in 1993, describes a head-mounted display and admits the risk of 'a bad feeling just like motion-sickness.'

Raytheon's US patent 5829446 confirms that even in 1996, when the patent was filed, 'cybersickness has become substantially more prevalent as people use high fidelity simulators to travel through computer-generated environments' and warns of 'cybersickness flashback, the sudden onset of simulator sickness symptoms in a simulator user who is no longer in a simulation environment.'

…but few 'cures'

'Numerous universities, consulting firms, technology companies and entertainment companies have vigorously investigated and attempted to reduce simulator sickness' Raytheon wrote in 1996. 'Methods for reducing simulator sickness have included increasing video update rates, adding motion bases to provide physical sensations to coincide with the video image, adding or improving sound

Searching for a VR motion sickness cure – *continued*

systems, improving video fidelity, introducing distracting objects to scenarios, providing depth through use of lenticular displays, slice stacking, binocular displays, repeated or prolonged exposure to induce physiological or psychological adjustment, and medication.'

Raytheon adds: 'The numerous prior investigations have yet to develop complete solutions for elimination of simulator sickness, but a number of studies have addressed specific ill effects with specific solutions and have identified previously unknown varieties of simulator sickness.'

One of the more recently published applications was filed by Sony. 2016/0246057, with the inexplicit title 'Image Display Device and Image Display Method, Image Output Device and Image Output Method, and Image Display System'. It says: 'Head-mounted displays are extremely popular (and) if mass production advances further in the future, head-mounted displays may become as common as mobile phones, smartphones, or handheld game consoles, and everyone may come to own their own head-mounted display.'

'The causes of VR sickness are various' the patent further explains, '… when an image with a wide range provided by an image output device is viewed over a narrow field on the side of the image display device, or when an image with a narrow range provided by an image output device is viewed over a wide field on the side of the image display device, distortion remains and readily induces VR sickness.'

Sony's aim is 'reducing VR sickness… (by) correcting the mismatch between the field of view of the provided image and the field of view experienced by the viewer.'

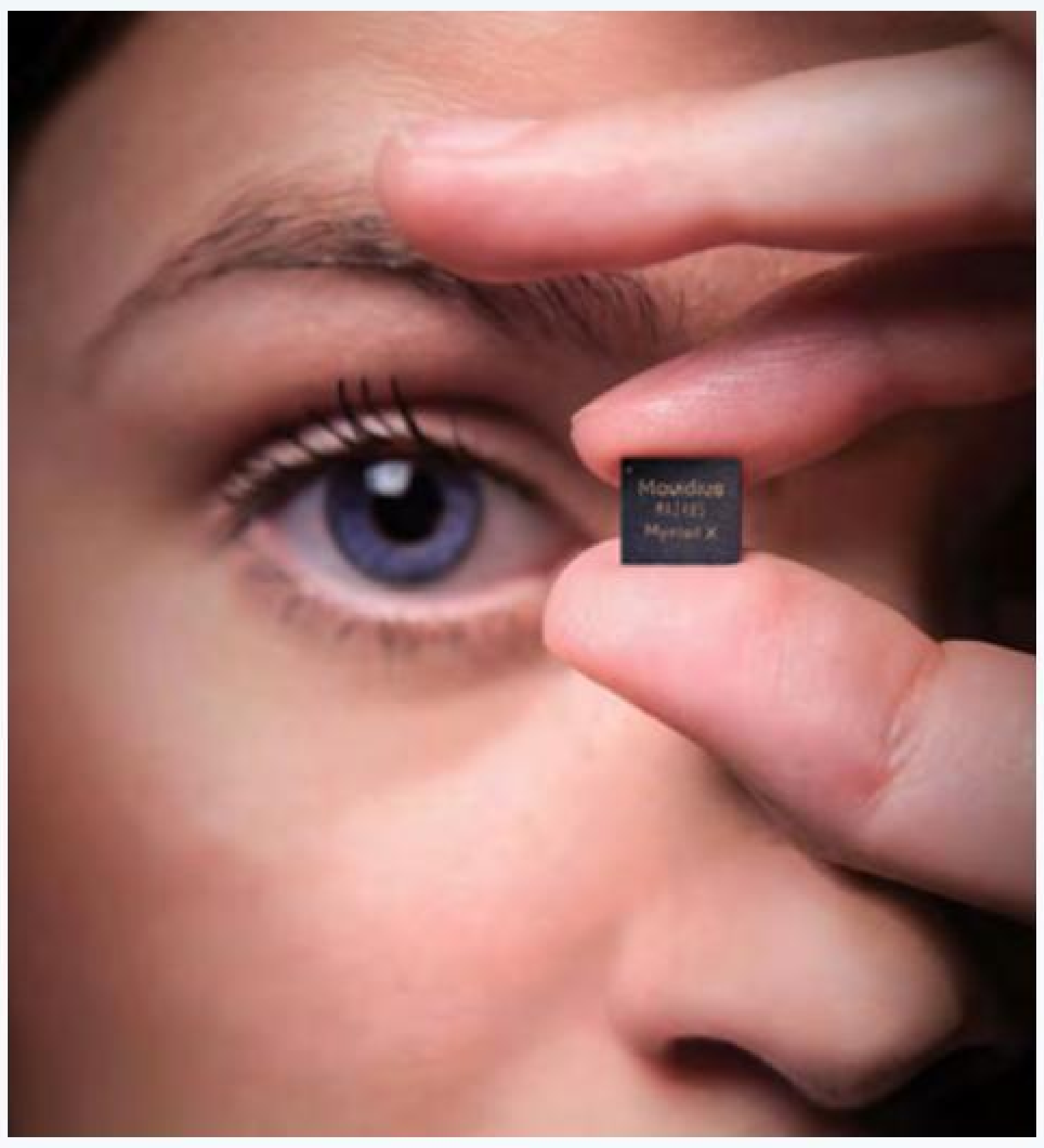
Each user personalises their head-mount viewer, with the result stored in standard format EDID (extended display identification data). The head mount then automatically tailors all VR images it displays. When the field of view of the VR image is too large the device cuts out and displays only a central region; when the VR field of view is smaller, the display adds black margins or wallpaper to fill the edge gaps, or stretches the images to fit. Either way the field of view of the VR images matches the user's field of view.

As a result, 'it is possible to greatly reduce VR sickness in the user (and) it is possible to display images from the first-person view or images with a wide field of view while reducing VR sickness.'

Intel unveils neural compute engine to unleash AI

Intel has introduced its new Movidius Myriad X vision processing unit (VPU), advancing its portfolio of artificial intelligence (AI) IC solutions to deliver more autonomous capabilities across a wide range of product categories, including drones, robotics, smart cameras and virtual reality.

Myriad X is the world's first commercially available system-on-chip (SOC) with a dedicated neural compute engine for accelerating deep learning inferences. The engine is an on-chip hardware block specifically designed to run deep neural networks at high speed and low power without compromising accuracy, enabling devices to see, understand and respond to their environments in real time. It enables Myriad X architecture to have 1 TOPS (trillion operations per second) of compute performance on deep neural network inferences.



'We're on the cusp of computer vision and deep learning becoming standard requirements for the billions of devices surrounding us every day,' said Remi El-Ouazzane, vice president and general manager of Movidius, Intel New Technology Group. 'Enabling devices with humanlike visual intelligence represents the next leap forward in computing. With Myriad X, we are redefining what a VPU means when it comes to delivering as much AI and vision compute power possible, all within the unique energy and thermal constraints of modern untethered devices.'

UK offshore wind prices tumble

Whatever your preferred flavour of electronics, from PIC projects to valve power amplifiers, you are dependent on a reliable source of electricity. We are spoilt for choice when it comes to how to generate electrical power, but an increasingly important source of 'fuel' is the wind. The UK has 45% of the best available wind energy resource in Europe and over the next four years an estimated £17.5bn will be invested in UK wind energy infrastructure.

On top of this funding, the wind energy industry got a vital boost in September. RenewableUK, the UK's offshore wind energy trade association reported a dramatic fall in the cost of electricity generated offshore following the results of the most-recent auctions for new contracts to provide nearly 4GW of clean electricity, enough power for 3.3 million homes.

The cost of offshore wind electricity has plummeted since the last competitive auction results were announced in February 2015, with the new prices on average 47% lower than they were just over two and half years ago. The prices – some as low as £57.50/MWhr – are cheaper than the cost of the 35-year contracts for new nuclear power of £92.50/MWhr, and cheaper than the levelised cost of gas, according to figures from the Department of Business, Energy and Industrial Strategy.

Pi cubed

True, it isn't the first, or the fastest Rubik's cube solver, but the machine demonstrated and explained at **http://bit.ly/2xI2s7L** has a real elegance that is well worth watching. Plus, it is driven using a Raspberry Pi 3 via a Compute Module Development Kit, which just goes to show that the Pi is not just for slow, simple processing, but is capable of some pretty sophisticated multitasking – in this case, driving multiple motors and running the solution algorithm in real time.

And for those of you who like to mix a little Meccano with your electronics, this version will inspire you: **https://youtu.be/C9rCBjLGxJs**

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TechnoTalk

Mists and mellow fruitfulness

Mark Nelson

Ah, the simple joys of autumn! Trees carpet the ground with crunchy golden leaves and park keepers sweep up the newly shed foliage and burn it on bonfires, the pleasant smoke wafting on the gentle breeze.

IT'S NICE TO WAX LYRICAL AND get out more at this time of year, although not without issuing a health and safety warning, because those gently smouldering leaves are almost certainly carcinogenic. They generate large amounts of airborne particulates that can reach deep into lung tissue, releasing polycyclic aromatic hydrocarbon compounds that cause lung cancer, as well as carbon monoxide that can bind with haemoglobin in the bloodstream and reduce the amount of oxygen in the blood and lungs. However, not all of the delightfully elegant trees that we see are what they appear to be.

Fake trees

No, this is not another one of Donald Trump's rants. In fact, it's not a rant at all, just a gentle invitation to go tree spotting now that the falling foliage is making it easier to observe the local treescape. But this is not a nature ramble, more of a field trip to suss out some highly unnatural trees that perform a very useful everyday electronic function. Thanks to one of our loyal and highly observant readers in leafy Sevenoaks, we can report that there's a suspicious-looking, bolt-upright dead tree beside the A225 main road at a reservoir in Sevenoaks that you can view by going to: **https://goo.gl/maps/CGB6ijTMBXu**

Meanwhile, in Gracious Lane, overlooking the Sevenoaks bypass, you can see a couple of telegraph poles (curiously lacking any wires or arms) desperately trying to look inconspicuous, rather like Trump's plain-clothes bodyguards fiddling with their hidden earpieces and muttering into the lapels of their smart suits... **https://goo.gl/maps/MMJcaojuLsQ2**

Furthermore, on the other side of the same road there grows a lofty mobile phone tree, visible at dead centre in **https://goo.gl/maps/LfR35UgYEk72** (*Pinus sylvestris var. telephonicus*). Or to see all three imposters together, glance at: **https://goo.gl/maps/Y1CgjxFjfYG2** – these species are not unique to Sevenoaks and can be spotted all over the UK and the world.

Barely believable

So what are these ungainly and unconvincing structures? – cellular base stations of course, which, as the Mobile Operators Association states, are sited whenever possible with a view to avoiding being a blot on the landscape. In sensitive areas, base stations can be disguised as trees, telegraph poles or street lamps. Unfortunately, even the best artificial trees (nearly always Scots pines) do not look very plausible, while the telegraph poles bizarrely have climbing steps only at the very top of the poles, far out of reach of any ladder that a lineman might notionally prop up against the 'pole'. In fact, the proportions of the poles just look plain 'wrong'; see: **http://bit.ly/2wHkwxL**

Bigger budgets mean they can do disguised antennas bigger and better in the US, with some extremely realistic palm trees and landmark cactus plants. Some cell towers are even camouflaged as works of sculptural art or hidden within church towers and crucifixes. There's a superb gallery of grandiose creations (and some miserable fails) at: **http://bit.ly/2x2GPxw**

Low and mighty

Is there any alternative to obtrusive base stations? The answer is 'yes', according to Vodafone, the UK's third-largest operator (with a 25 per cent market share) and EE ('everything everywhere', except where you happen to live, according to users in Borehamwood where Global Wireless Solutions found that 36 per cent of calls fail). First off, let's take Vodafone's solution, called Mini Macro. This is an 'oven-ready' package of all the various elements of a base station – including transmission, power and radio equipment – located in a single housing. Being pre-configured for easy installation, it takes just hours to set up, requiring only to be concreted in place and connected to optical fibre and power.

According to Kye Prigg, head of mobile networks at Vodafone UK, Mini Macro could revolutionise the way we move forward with rural and hotspot coverage. It's about 50 per cent cheaper than a normal deployment, yet it brings the same capacity. Thanks to its reduced footprint, Mini Macro is less likely to fall foul of planning restraints – which Vodafone acknowledges is an issue in rural areas, even when there is a need for improved connectivity.

Up, up and away...

... in my beautiful balloon. EE's innovation is no flight of fancy, but an 'air mast' or 'helikite'. Announced earlier this year and demonstrated successfully at the Oval Cricket Ground in London, this is a mini 4G mobile base station built into a (tethered) helium balloon that can be deployed at short notice to connect the most remote parts of the UK and keep communities online in the wake of disasters such as major flooding. EE has also showcased the use of drones equipped with mini cellsites, each including a base station and antenna that could be used to provide targeted coverage for, say, search and rescue operations. EE has also demonstrated the use of small conventional cells connected back into the main EE network by satellite.

Marc Allera, the company's CEO comented: 'We are going to extraordinary lengths to connect communities across the UK. Innovation is essential for us to go further than we've ever gone, and deliver a network that's more reliable than ever before. Rural parts of the UK provide more challenges to mobile coverage than anywhere else, so we have to work harder there.

'Looking ahead, I see innovations like this revolutionising the way people connect. We're developing the concept of 'coverage on demand'. What if climbers going up Ben Nevis could order an EE aerial coverage solution to follow them as they climb? We need to innovate, and we need to think differently, always using customers' needs to drive the way we create new technologies.'

Indeed, they do need to and hopefully EE, which claims the largest 4G coverage in the UK, will now extend this to Borehamwood by installing a few of its helikites above this neglected notspot of 31,000 long-suffering inhabitants.

One for nomads...

50A Battery Charger Controller

For 12/24V 'house' batteries

Are you one of the many thousands doing a grand trek in an RV, caravan or campervan? Then you will know the problems with trying to charge up your 'house' batteries during a long trip. This heavy-duty charger controller will enable you to charge those batteries much more quickly using your portable generator and a low-cost 40A or 50A charger.

Even if your RV, caravan or campervan has a couple of solar panels on the roof, getting your 'house' batteries (ie, the one[s] in the aforementioned RV, caravan or camper, as distinct from your vehicle battery) quickly up to charge can be a real problem, especially if you arrive at a remote campsite late in the day.

If you want power, there is no alternative to dragging out your portable generator and using it to charge your batteries.

The big problem is that the limited 12V, typically 5A DC output from the generator's inbuilt charger can take forever to bring house batteries up to charge.

That means running the generator for many hours – and that is not desirable at all.

The idea for this project came to us from a 'nomad' some time ago. Instead of trying to charge from his generator's 12V output, he suggested using a cheap 40A charger, powered by the 230VAC from the generator. That would bring the batteries up to charge in a fraction of the time. Consequently, the generator would only need to run for a much shorter time.

What a great idea! The portable generator is used much more efficiently, it uses a *lot* less fuel and you don't have to listen to the generator droning away for hours on end (nor do the other people who may be camping at the same site).

However, there is a drawback with the idea (which was noted by the nomad). If you don't monitor the battery voltage closely, there is a considerable risk of overcharging and ultimately, boiling the batteries.

A multi-stage charger won't necessarily solve this since, depending on its design, during the absorption phase it may hold the battery at a high enough voltage for long enough to cause vigorous boiling of the electrolyte.

There is even a danger of a battery explosion with the emission of hydrogen during over-charging.

Our project removes those risks. It monitors the battery while it is being charged and when the voltage comes up to a preset value, say 14.4V, it disconnects the charger.

Better still, about five seconds after that, it switches off the generator to restore the serenity.

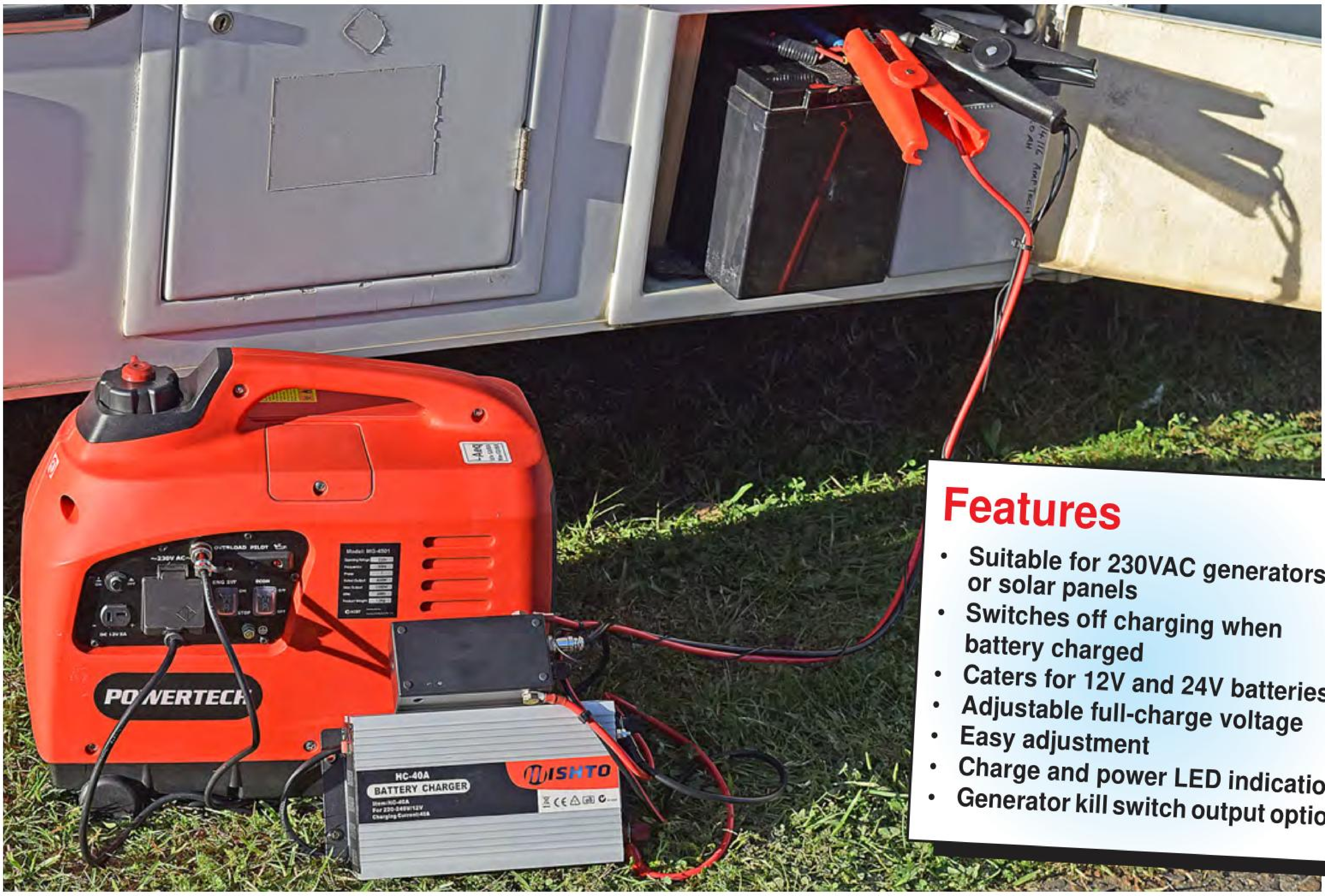
And best of all, it removes the need to watch the batteries yourself, so you can get back to the more serious campsite task . . . of relaxing and enjoying yourself!

We should note that many modern switchmode chargers do incorporate proper 3-state or multi-state charging, and so they may safely terminate the charge in a float condition.

However, if you have large house batteries, say 200Ah or more, then even with a 40A charger it will take many hours to bring them up to full charge. In that case, you might elect to only bring the batteries up to the 'bulk charge' state, then terminate the charge and switch off the generator. Our *50A Charger Controller* will allow you to do that.

Of course, this *50A Charger Controller* can be used if you *do* have mains power on the campsite. Then you don't need to fire up the generator – just hook up the high current charger and our *50A Charger Controller* to your house batteries and you can be sure that they will be brought up to full charge while you enjoy your idyllic surroundings.

Design by
JOHN CLARKE



Features

- Suitable for 230VAC generators or solar panels
- Switches off charging when battery charged
- Caters for 12V and 24V batteries
- Adjustable full-charge voltage
- Easy adjustment
- Charge and power LED indication
- Generator kill switch output option

Naturally, you don't have to be a nomad on a grand tour to consider building our *50A Charger Controller*. It can be used at any time with any basic charger which does not have 'end-of-charge' detection; most lower-priced ones don't.

So why don't basic battery chargers limit charging when the battery reaches full charge? The answer is that most, especially the lower-cost models, are *too* simple: all most have is a transformer and rectifier diodes.

Fig.1 shows two typical battery charger circuits, one using a centre-tapped transformer and two rectifier diodes, or a single winding transformer with a four-diode bridge rectifier. Both feed rectified but unfiltered DC to the battery.

The batteries are quite happy to be charged with this pulsating DC; the problem occurs when charging is complete. The charger doesn't know, so it keeps on pushing current in. The battery overcharges and . . .

Similarly, if you have a bank of solar panels to charge a 12V or 24V battery, there is the same risk of over-charging. Our *50A Charger Controller* can also prevent that from happening.

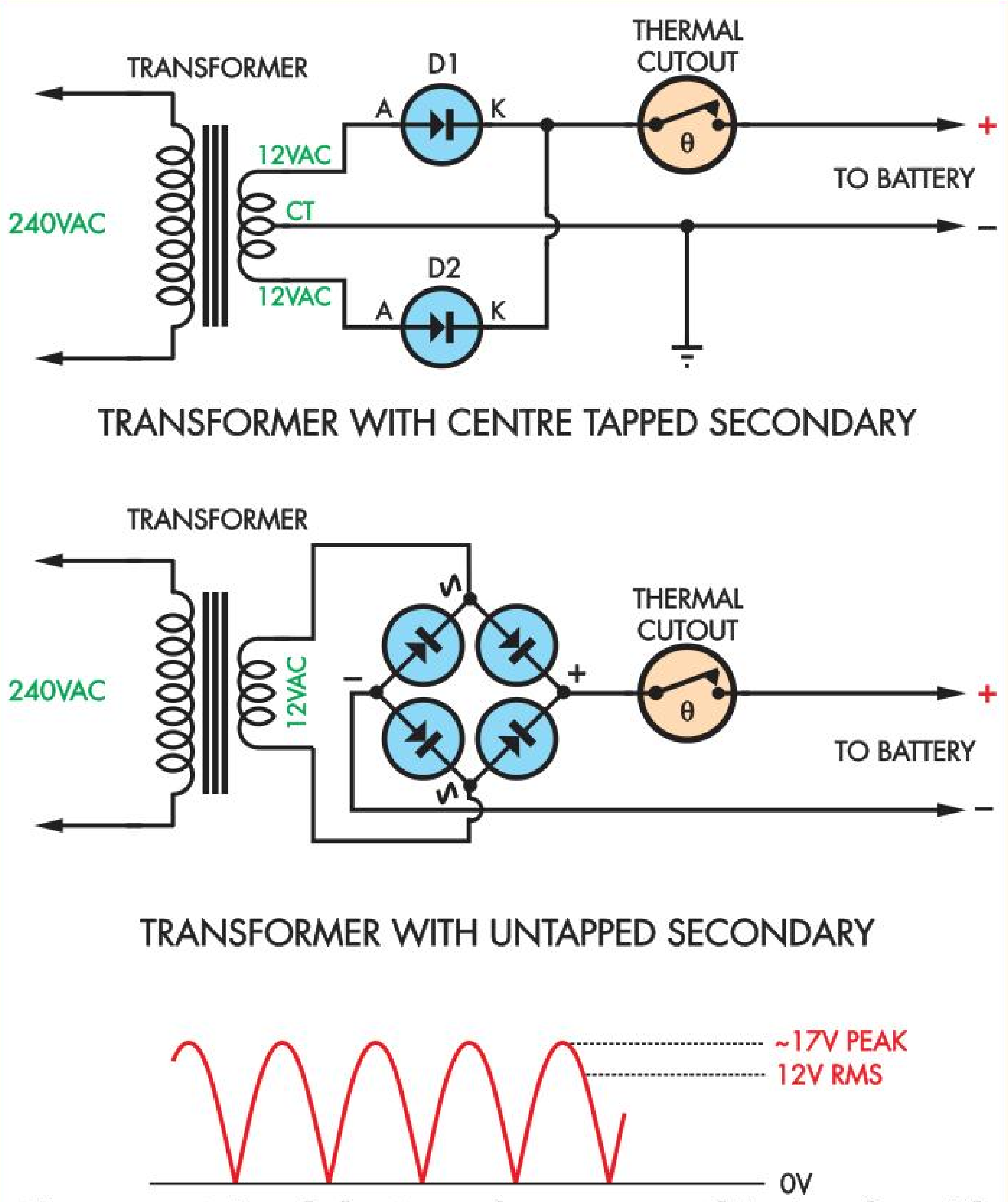


Fig.1: most simple battery chargers *are* this simple, with only a transformer, rectifier and thermal cutout. It's the peak voltage that actually does the charging.

Circuit concept

In essence, the *50A Charger Controller* is connected in series with the positive lead of the charger to the battery. The controller has a 60A automotive relay which disconnects the charger when the battery comes up to charge, all under the control of a PIC12F675 microcontroller. A second, smaller relay shorts a pair of wires from the kill switch on the generator. So it's a pretty simple concept, as shown in Fig.2.

Fig.3 shows the full circuit. You can see the red conductor from the charger positive output at the top right-hand corner of the diagram. It passes through the contacts of the 60A relay and then out to the positive terminal of the battery being charged. The output to the battery is also fed to an LM2940CT-12 3-terminal 12V regulator, which produces 12V to power the two relays, RLY1 and RLY2.

On the left of the circuit, the charger output is fed via diode D3 to an LM317 adjustable 3-terminal regulator, which provides 5V DC to run the PIC12F675 microcontroller, IC1.

The PIC monitors the battery voltage to detect the end of charge and it controls the relays and drives the charge indicator, LED2.

12V or 24V batteries

This *50A Charger Controller* works with 12V or 24V chargers and lead-acid batteries. The battery voltage is measured

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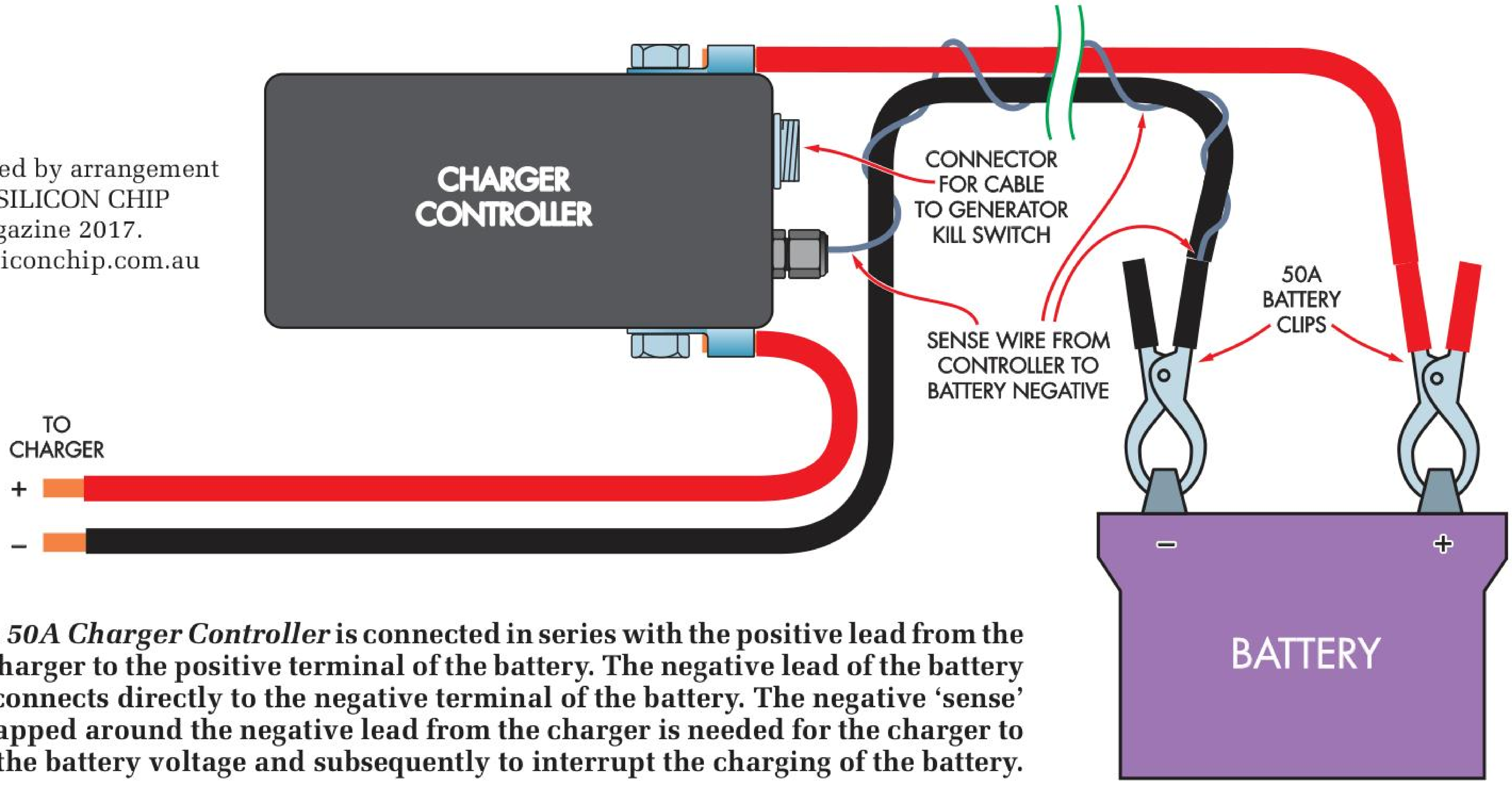
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CONNECTOR FOR CABLE TO GENERATOR KILL SWITCH
50A BATTERY CLIPS
SENSE WIRE FROM CONTROLLER TO BATTERY NEGATIVE
TO CHARGER
+
–
–
+
BATTERY

Fig.2: the *50A Charger Controller* is connected in series with the positive lead from the battery charger to the positive terminal of the battery. The negative lead of the battery charger connects directly to the negative terminal of the battery. The negative 'sense' wire, wrapped around the negative lead from the charger is needed for the charger to monitor the battery voltage and subsequently to interrupt the charging of the battery.

using a voltage divider comprising a 100kΩ resistor from the battery positive and two series-connected 22kΩ resistors connecting to 0V. Total resistance is 144kΩ. The 22kΩ resistors provide a reduced voltage suitable for IC1 to measure battery voltage at its AN1 input. IC1 requires a voltage at its AN1 input of less than the supply of 5V and the voltage divider caters for both 12V and 24V batteries by changing over a jumper link that selects one of two positions in the voltage divider. Diode D4 protects against reverse battery connection.

In the 12V position, the divider connection with jumper (JP1) comprises a 44kΩ resistance (with the two 22kΩ in series) and the 100kΩ resistor with a division ratio of 44/144. This reduces 12V down to 3.666V. At full charge, the battery is around 14.4V and so the divided voltage is 4.4V.

For the 24V position, the jumper selects the lower 22kΩ resistor and so the division ratio is 22/144. The reduced voltage becomes 3.666V when the battery is at 24V. At full charge of 28.8V, the divided voltage is once again 4.4V.

Note that the reduced voltage that is applied to the AN1 input of IC1 is the same for both 12V and 24V batteries. This means that IC1 can detect full charge for either a 12V or 24V battery just by changing the position of link JP1. Instead of using a jumper shunt to select 12V or 24V, an SPDT toggle switch on the front panel could be used in its place.

The battery is deemed to be fully charged when the AN1 input rises above the AN0 input. The AN0 input is connected to a voltage divider across the 5V supply, comprising a 5kΩ trimpot (VR2) and associated resistors in series to 0V.

VR2 is adjusted to set the required full-charge voltage for the battery. For a 12V battery, VR2 is adjusted to obtain 1.44V, measured between TP1 and GND, resulting in 4.4V at the AN0 input. For a 24V battery, (with a full charge voltage of 28.8V) set VR2 for 2.88V between TP2 and GND.

Note that the GND terminal is connected to the negative terminal of the battery. Without this connection, the *50A Charger Controller* cannot work.

Relay RLY1 is controlled by the GP2 output of IC1, and this drives the base of transistor Q1, which turns on the relay.

Relay RLY2 is controlled via the GP4 output and transistor Q2. Diodes D1 and D2 are included to clamp the voltage spikes, which are generated when the relays are turned off. If the diodes were omitted, there would be a risk that Q1 and Q2 could be damaged by the high voltage spikes.

SPECIFICATIONS

Supply	12V or 24V battery charger
Charger current	Up to 50A
Charge voltage	Adjustable from 13.87V to 16.36V for 12V battery and 27.74V to 32.73V for 24V battery
Battery drain	With charger off, ~10mA
Kill switch output	Contacts close for 5s, 5s after charging is completed

Charging sequence

IC1 monitors the battery at the AN1 input and switches on relay RLY1 if the battery voltage is over 9V (or over 18V for a 24V battery). The relay contacts then pass the charging current from the charger to the battery.

When the battery reaches full charge, the relay switches off to disconnect the charger. The battery is then continuously monitored and relay RLY1 will be switched on again if the battery voltage drops to 12.5V or below, for a 12V battery, or below 25V for a 24V battery.

Of course, if the charger is fed by a portable generator and the kill switch lead is connected, the generator will have been turned off and will have to be manually restarted for charging to re-commence.

The charging indicator (LED2) flashes once each second during charging, and stays fully on once the battery is fully charged. LED2 is off when the battery is disconnected (ie, below 10V or 20V). LED1 is on whenever the charger is on.

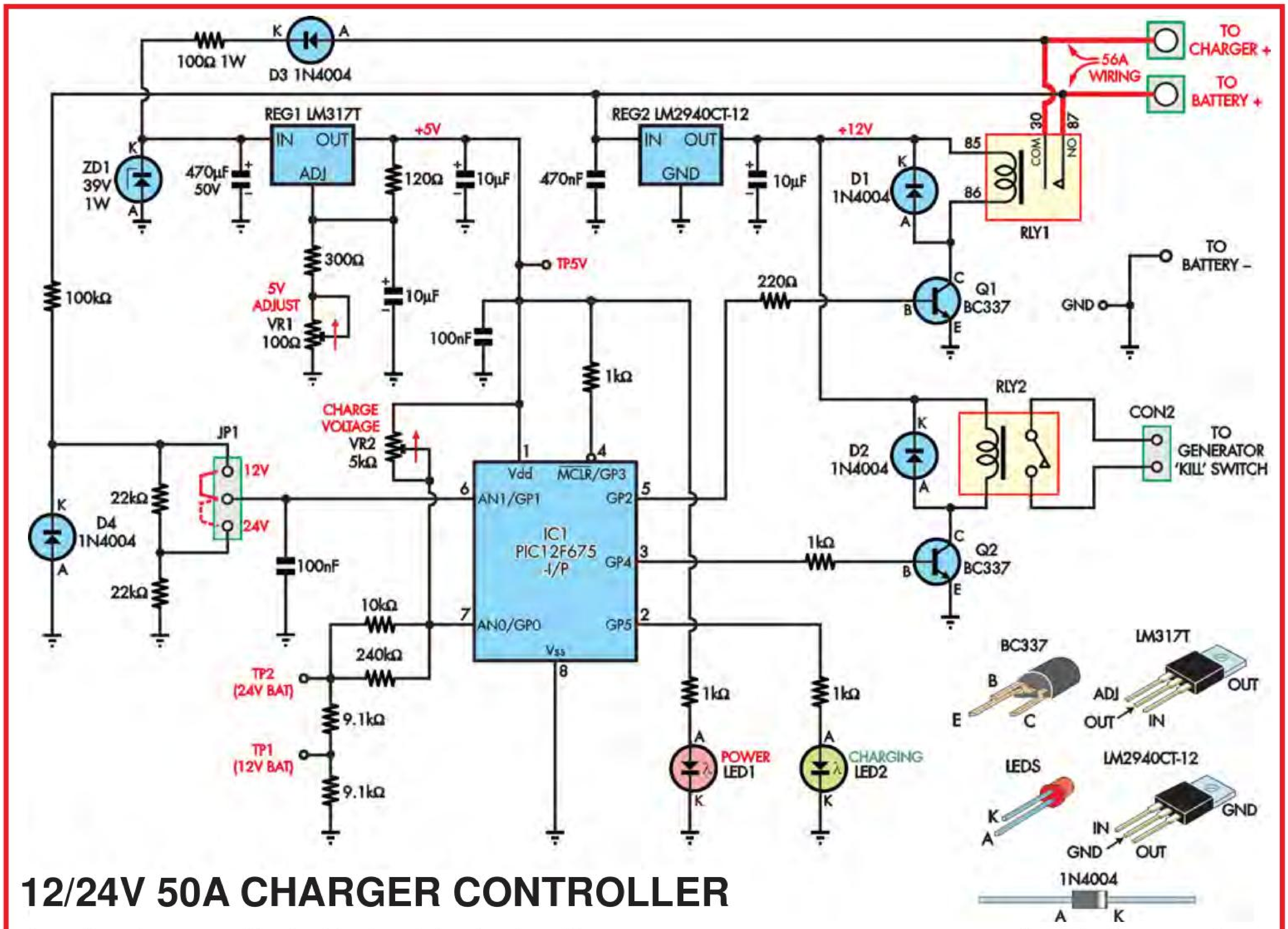
Kill switch relay

Relay RLY2 is included to switch off the generator once the battery charger has been disconnected by the main relay, RLY1. Relay RLY2 is switched on five seconds after RLY1 switches off, for five seconds. The kill switch lead is connected to a socket (which needs to be installed) on the generator, in parallel with the contacts of the generator's engine (kill) switch.

Construction

All the components of the *50A Charger Controller* are assembled onto a PCB coded 11111161, measuring 122 × 53.5mm, which is available from the *EPE PCB Service*. It is housed in a UB3 plastic case measuring 130 × 68 × 44mm.

Before installing components on the PCB, place it


100Ω 1W
K
A
D3 1N4004
TO CHARGER +
56A WIRING
TO BATTERY +
REG1 LM317T
IN
OUT
ADJ
+5V
REG2 LM2940CT-12
IN
OUT
GND
+12V
ZD1 39V 1W
470µF 50V
120Ω
10µF
470nF
10µF
D1 1N4004
85
86
30
87
COM
NO
RLY1
300Ω
TP5V
TO BATTERY –
5V ADJUST VR1 100Ω
10µF
220Ω
Q1 BC337
GND
100kΩ
100nF
1kΩ
RLY2
CON2
CHARGE VOLTAGE VR2 5kΩ
1
4
TO GENERATOR 'KILL' SWITCH
JP1
12V
24V
D2 1N4004
Vdd
MCLR/GP3
6
5
AN1/GP1
GP2
22kΩ
D4 1N4004
IC1 PIC12F675 -I/P
GP4
3
1kΩ
Q2 BC337
100nF
22kΩ
10kΩ
7
AN0/GP0
GP5
2
Vss
8
240kΩ
TP2 (24V BAT)
9.1kΩ
TP1 (12V BAT)
9.1kΩ
1kΩ
1kΩ
POWER LED1
CHARGING LED2
B
C
E
BC337
LM317T
ADJ
OUT
IN
LEDS
LM2940CT-12
GND
IN
OUT
1N4004

12/24V 50A CHARGER CONTROLLER

Fig.3: the microcontroller in this circuit (IC1) primarily acts as a comparator. It compares a sample of the battery voltage (at its AN1 input, pin 6) with a reference voltage at its AN0 input, pin 7. When the voltage at pin 6 rises above that at pin 7, IC1 switches on transistor Q1, to actuate relay RLY1 and interrupt the charge.

in the plastic case and mark out the position for the corner mounting points on the base.

Fig.4 shows the component overlay of the PCB and the battery negative terminal and the kill switch socket. Fig.5 shows the heavy-duty wiring for the connections to the battery and charger.

Begin assembly by installing the resistors, using a multimeter to check the value of each before inserting it. Diodes D1-D4 and the zener diode ZD1 can be installed. These must be oriented as shown and be careful not to mix the diode types.

(By the way, if you don't want to use the kill switch facility, you can omit the components associated with it, ie, connector CON2, the 2-pin socket, relay RLY2, diode D2, transistor Q2 and its 1kΩ base resistor). On second thoughts, you probably should install them because after you use it, you'll wonder why you didn't have the auto-kill facility!

PC stakes can then be installed at test points GND, TP5V, TP1, TP2 and the relay terminal connections labelled 30, 87, 85 and 86 and the four LED connections.

Install the 3-way header for JP1. (Normally, a jumper shunt is placed on the 12V or 24V battery position). If you intend to use the *50A Charger Controller* for 12V and 24V batteries, you may prefer to install an SPDT switch instead. Wire the switch directly to the header or via a 3-way plug.

Make sure you orient the socket for IC1 correctly and then install the capacitors. The electrolytic types must be oriented with the shown polarity.

The two 3-terminal regulators are mounted horizontally onto the PCB with their leads bent to fit into the PCB holes. REG2 is installed onto a small heatsink. Both regulators are secured using an M3 × 6mm screw and M3 nut.

The trimpots can be mounted next. VR1 is 100Ω (coded 101) and VR2 is 5kΩ (coded 502). Make sure they are oriented with the adjusting screw, as shown in Fig.4; that gives increasing voltages with clockwise rotation of the adjustment screws.

Relay RLY2 goes in next, but leave the main relay (RLY1) until the heavy-duty wiring is done.

Next, install the two LEDs. We mounted ours so that the top of the LEDs are 34mm above the PCB, which makes them visible through holes in the top lid of the case.

Before installing IC1, we recommend adjusting trimpot VR1 for a 5V output. To do this, connect a 12V supply between GND and the anode of diode D3. Then adjust VR1 for a reading of 5.0V between GND and TP5V.

To program IC1 download hex file 1111116A.hex from the *EPE* website; install the programmed PIC into its socket, making sure it is oriented correctly.

Before installing RLY1, the terminals numbered 30 and 87 will need to be wired to the 56A red cable. Cut two 90mm lengths of the cable and strip back the ends of insulation by about 5mm. Solder or crimp (or crimp and solder) one end of each wire to a large eyelet connector. The other ends of the cable are soldered to terminals 30 and 87.

Note that the soldering to the No.30 relay terminal should be made on the side that is near to the No.86 terminal to avoid any possible shorting to the No.87 PC stake on the PCB. Wire as shown in Fig.6. At the same time, solder short (30mm) lengths of hookup wire to each of the 30, 85, 86 and 87 terminals, ready to solder to the PC stakes on the PCB.

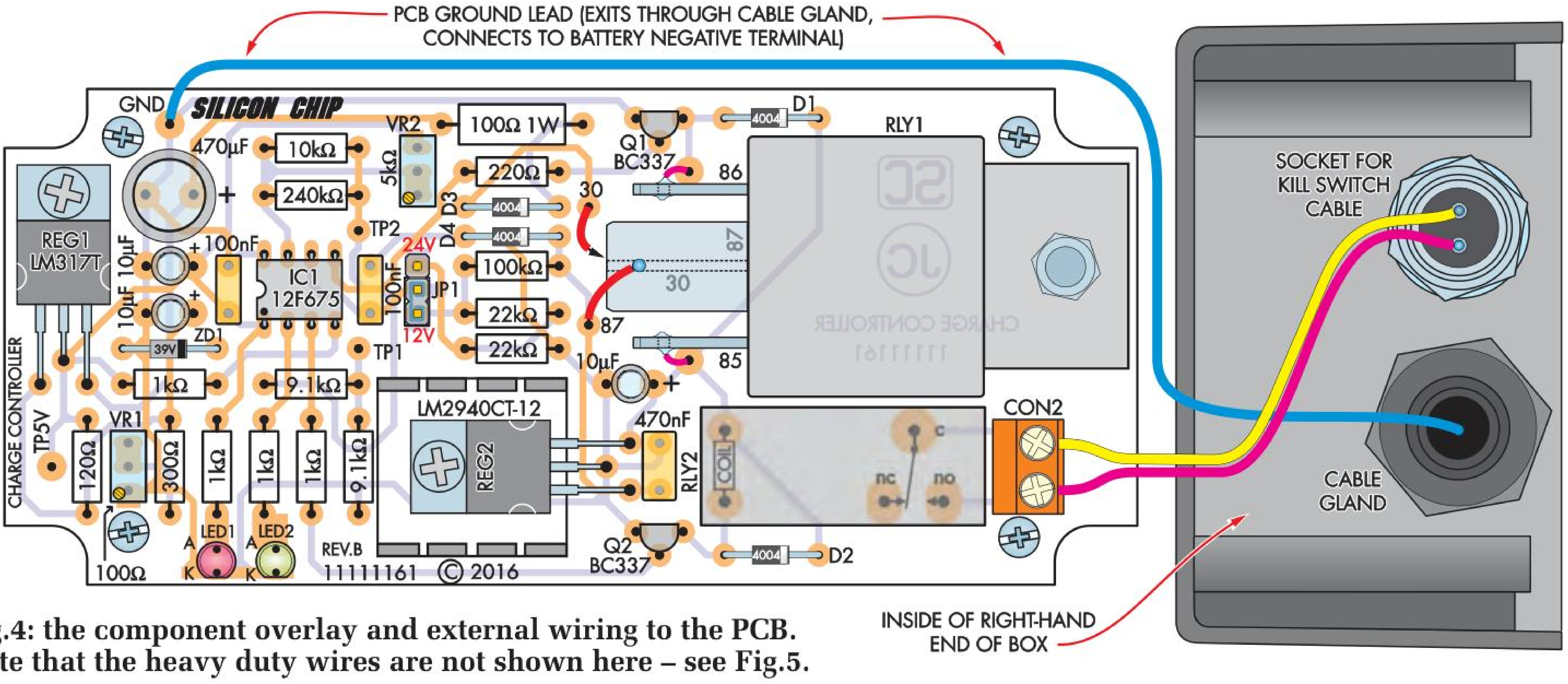

PCB GROUND LEAD (EXITS THROUGH CABLE GLAND, CONNECTS TO BATTERY NEGATIVE TERMINAL)
GND
SILICON CHIP
470µF
10kΩ
240kΩ
VR2
5kΩ
100Ω 1W
220Ω
Q1
BC337
D1
4004
RLY1
86
30
87
85
REG1
LM317T
10µF
100nF
IC1
12F675
TP2
24V
JP1
12V
TP1
D3
D4
100kΩ
22kΩ
ZD1
39V
1kΩ
9.1kΩ
VR1
120Ω
300Ω
TP5V
CHARGE CONTROLLER
LM2940CT-12
REG2
470nF
RLY2
COIL
c
nc
no
CON2
Q2
BC337
D2
LED1
LED2
A
K
REV.B
11111161 © 2016
100Ω
SOCKET FOR KILL SWITCH CABLE
CABLE GLAND
INSIDE OF RIGHT-HAND END OF BOX

Fig.4: the component overlay and external wiring to the PCB. Note that the heavy duty wires are not shown here – see Fig.5.

Cover the bare terminals with 10mm-diameter heatshrink tubing and solder the hookup wires to the PC stakes before securing the relay with an M5 bolt and nut.

The PCB is mounted on four 6.3mm standoffs at each corner of the PCB. Use the M3 × 5mm pan head screws to secure to the PCB. If you are wiring the kill switch output, its socket can be installed on the end of the case now.

Drilling the case

Drill out the four 3mm corner mounting holes in the base of the case where marked previously. Countersink the holes if you intend to use countersunk screws. Drill out holes in the sides for the two M8 screws and the cable gland. You may need to use a reamer to open out to the required diameter if you do not have a drill large enough.

The centre of the holes need to be near to the top edge of the box, but no closer than 12mm from the top. See Fig.5 for details.

As previously mentioned, the battery charger red (positive) wire for the positive connection on the battery needs to be cut and each end terminated to a large eyelet. These attach to the *50 Charger Controller*, as shown in Fig.2. The sense wire from the negative battery charger clip is passed through the end of the case via a cable gland. The wire wraps around the 0V charger wire and is connected to the charger's 0V battery clip. You should be able to solder or crimp the sense wire to the battery clip, or connect it via a crimp eyelet that is attached to the battery clip with a screw and nut.

Panel label

Front panel artwork can be downloaded from the *EPE* website. We have provided two versions: one as shown overleaf and the other with provision for a 12V/24V battery switch.

You have several options for producing a front panel label. One is to print it onto clear overhead projector film, using film suitable for your type of printer, and as a mirror image so the printed side is protected against the lid. With a black lid you need to attach the label with a light coloured silicone sealant, so the printing can be seen against the silicone.

Alternatively, you can print onto an A4-sized synthetic 'Dataflex' sticky label that is suitable for inkjet printers or a 'Datapol' sticky label for laser printers. (Google 'Dataflex' or 'Datapol' for more information).

Then affix the label using the sticky back label adhesive and cut out the required holes with a hobby knife.

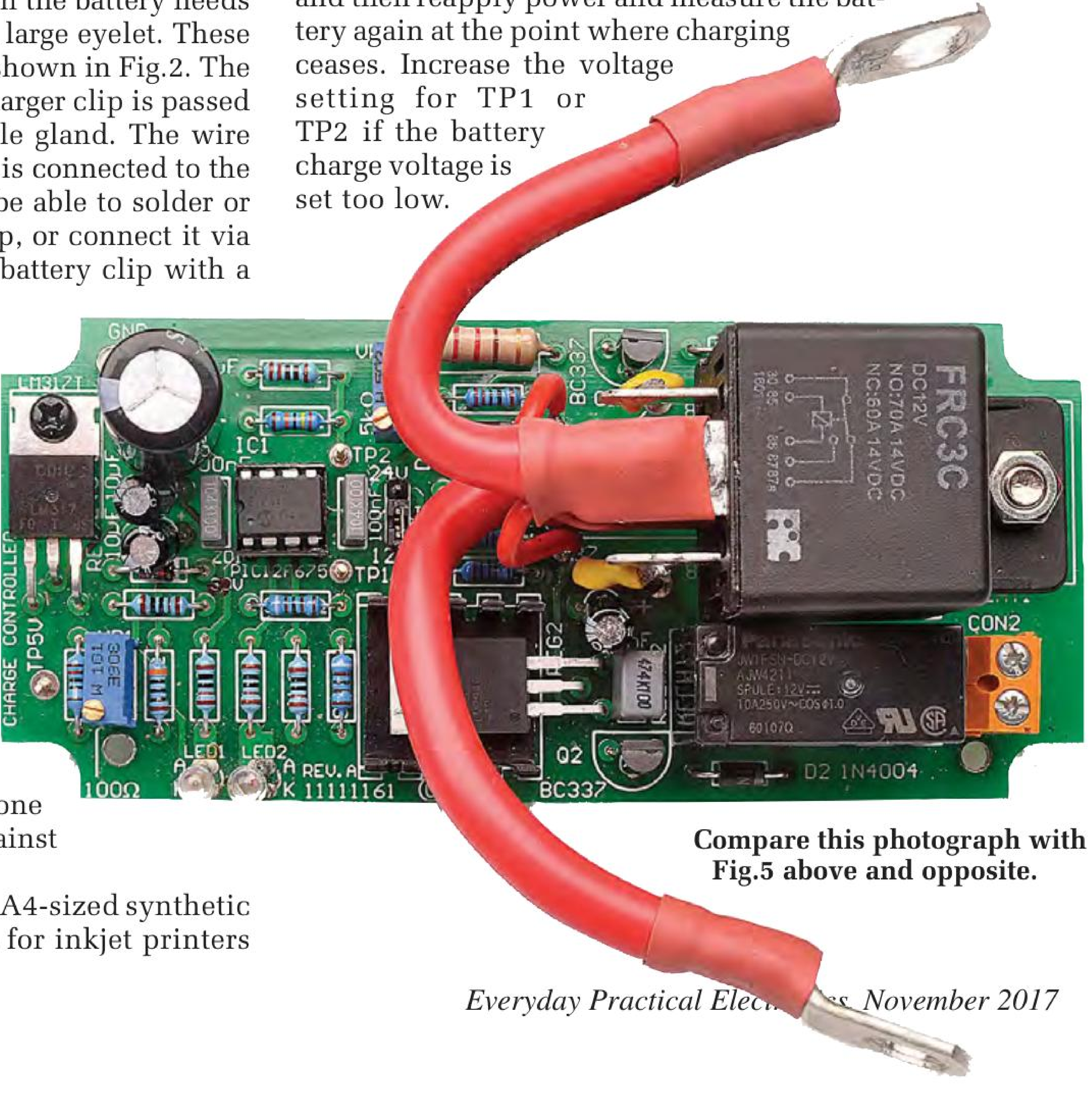
Setting the full-charge voltage

As mentioned, you would typically set the voltage at TP1 and TP2 to 1.44 and 2.88V. That gives a full-charge voltage of 14.4V for a 12V battery and 28.8V for a 24V battery.

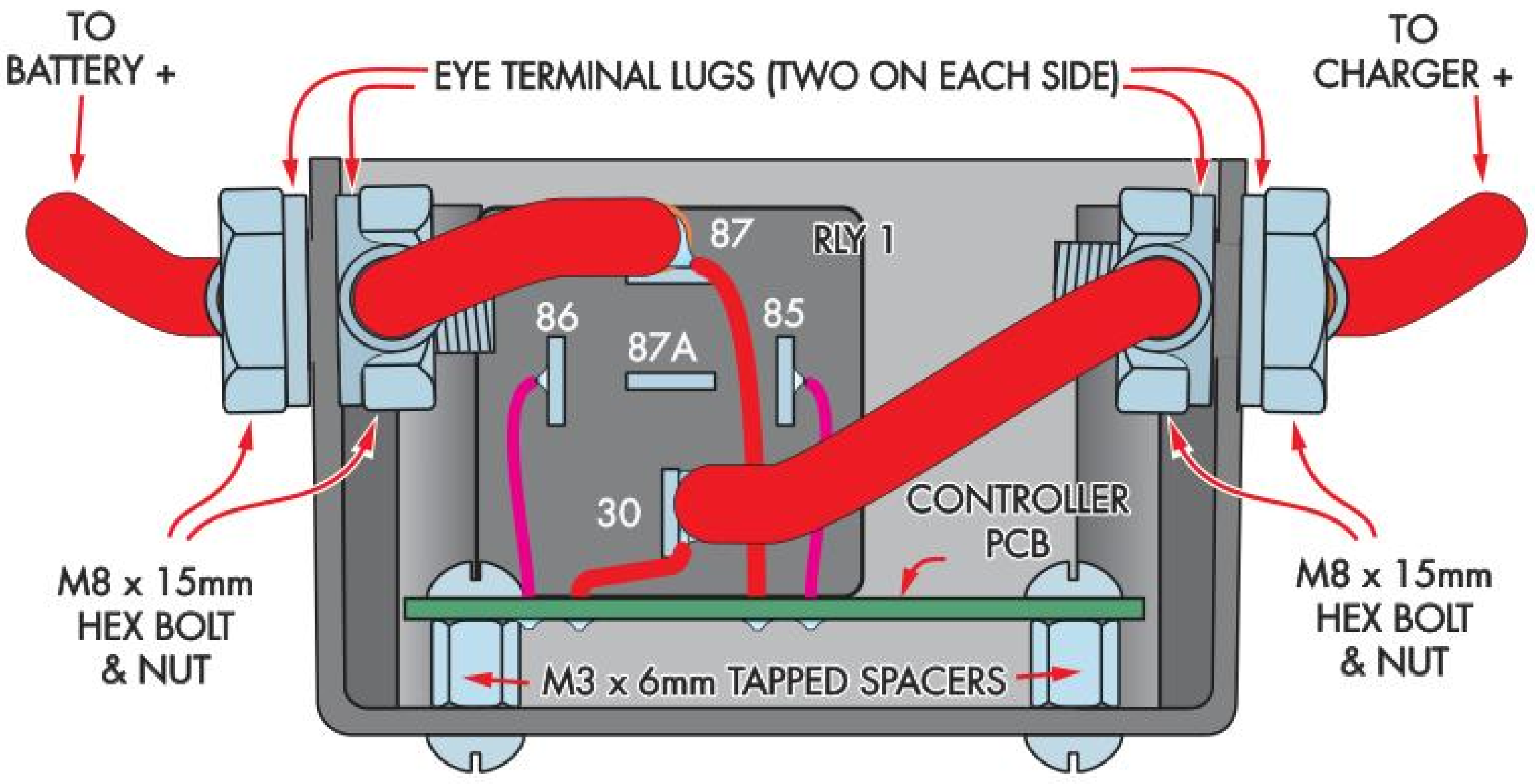
However, the manufacturer of the battery you are using may recommend a higher (say 14.8V) or a lower (say 13.9V) voltage for a 12V battery (and twice those figures for a 24V battery) and it might need to be reduced for elevated temperatures. Check with the manufacturer's specifications for details on how much reduction with temperature is required.

You can check the charge voltage by measuring the battery voltage as it reaches full charge and charging stops and the charge LED continuously lights.

If you missed the full-charge point, switch off the charger and then reapply power and measure the battery again at the point where charging ceases. Increase the voltage setting for TP1 or TP2 if the battery charge voltage is set too low.


GND
LM317T
IC1
TP2
24V
TP1
CHARGE CONTROLLER
TP5V
LED1
LED2
REV. A
11111161
100Ω
BC337
FRC3C
DC12V
CON2
Q2
BC337
D2 1N4004

Compare this photograph with Fig.5 above and opposite.


TO BATTERY +
EYE TERMINAL LUGS (TWO ON EACH SIDE)
TO CHARGER +
87
RLY 1
86
87A
85
30
CONTROLLER PCB
M8 x 15mm HEX BOLT & NUT
M8 x 15mm HEX BOLT & NUT
M3 x 6mm TAPPED SPACERS

NOTE: FIT HEATSHRINK SLEEVES OVER EACH CABLE ENTRY INTO ITS EYELET, ALSO OVER SOLDER JOINTS TO RELAY LUGS 87 & 30

Fig.5: this diagram shows the heavy-duty cables running from the relay (RLY1) to the eye terminal lugs, thence to the charger and the battery.

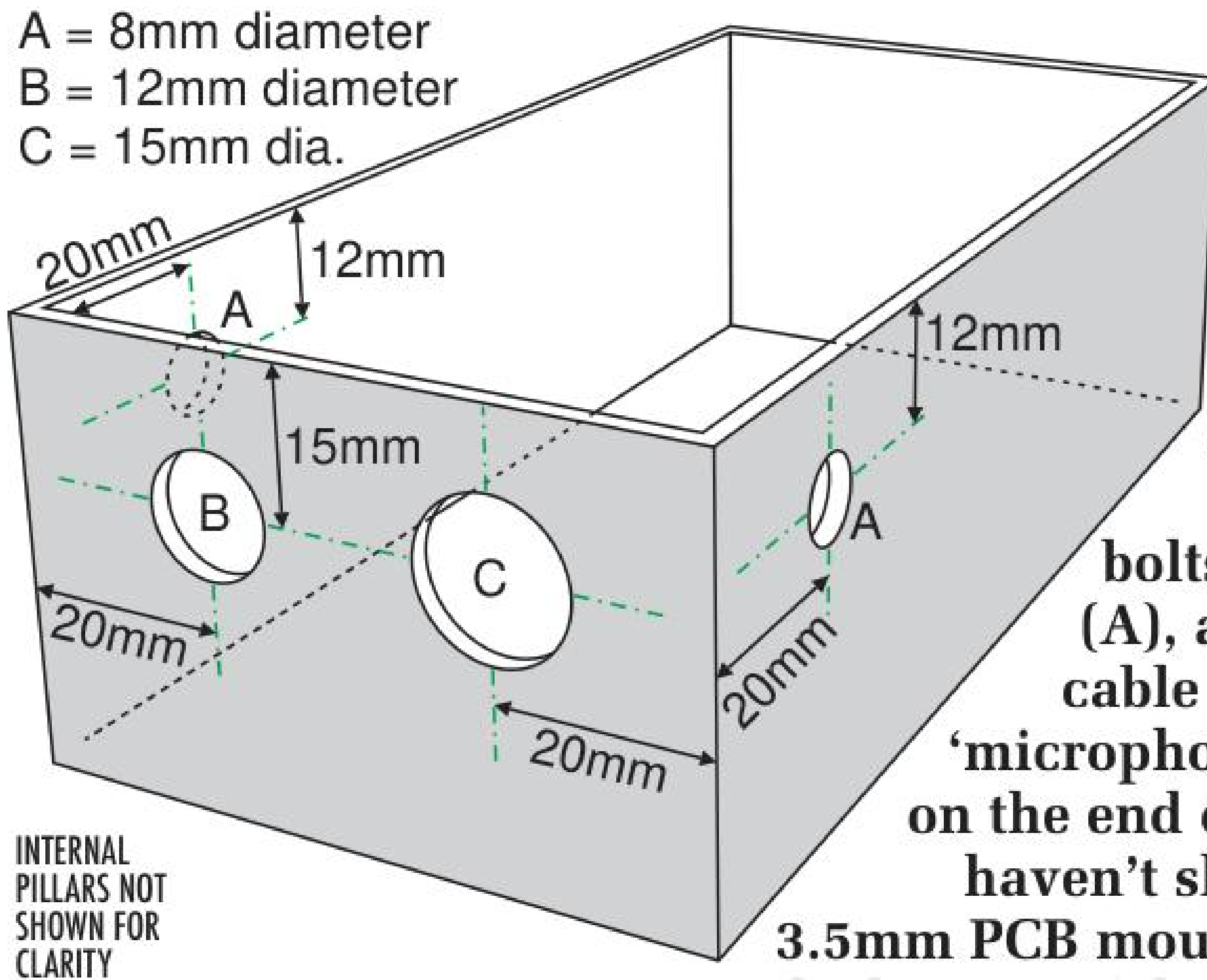
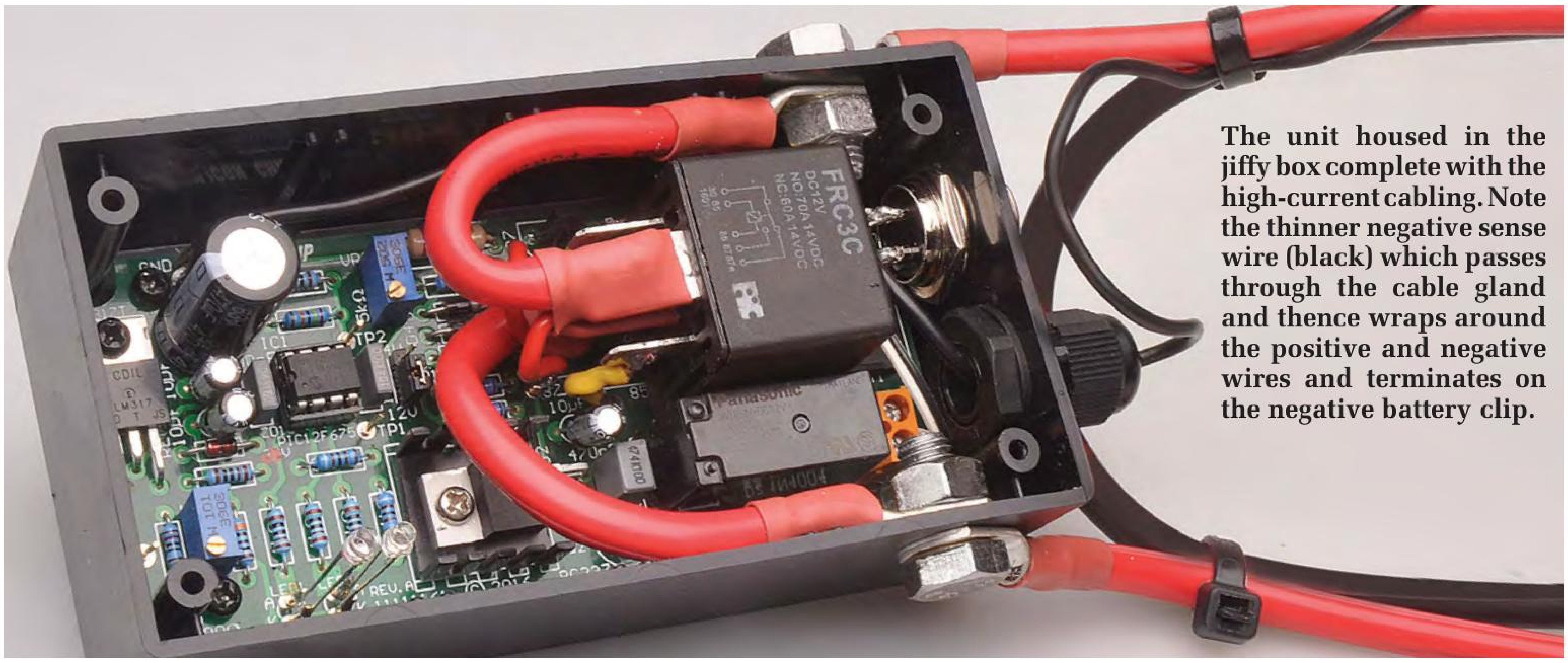

A = 8mm diameter
B = 12mm diameter
C = 15mm dia.
20mm
12mm
A
12mm
15mm
B
C
A
20mm
20mm
20mm
INTERNAL PILLARS NOT SHOWN FOR CLARITY

Fig.6: drilling detail for the 8mm bolts on each side (A), along with the cable gland (B) and 'microphone' socket (C) on the end of the box. We haven't shown the four 3.5mm PCB mounting holes in the bottom of the box – use the PCB itself as a template for these.



The unit housed in the jiffy box complete with the high-current cabling. Note the thinner negative sense wire (black) which passes through the cable gland and thence wraps around the positive and negative wires and terminates on the negative battery clip.

Parts list – 50A Charger/Controller

1 PCB available from the *EPE PCB Service*, coded 11111161, 122 × 53.5mm
1 UB3 plastic case, 130 × 68 × 44mm
1 panel label, 120 × 60mm
1 12V 60A automotive relay (RLY1)
1 SPDT 12V 10A relay (RLY2)
1 2-way screw terminal, 5.08mm spacing (CON2)
4 eye terminals with 8mm eyelet hole, for 10mm^2 wire
1 180mm length of 56A red automotive cable
1 2m length of medium duty black hookup wire
1 TO-220 heatsink, 19 × 19 × 9.5mm
1 8-pin DIL IC socket
1 cable gland for 3-6.5mm diameter cable
1 3-way header with 2.54mm spacings (JP1)
1 pin header shunt (for JP1)
1 SPDT toggle switch (S1) (optional – used instead of JP1 shunt)
2 2-pin chassis-mount male microphone sockets
2 2-pin female microphone plugs
2 M8 × 16mm bolts and nuts (NB: NOT PASSIVATED)
1 M5 × 10mm bolt and nut (to secure RLY1)
4 M3 tapped 6.3mm standoffs (for PCB mounting)
8 M3 × 5mm pan head screws (or 4 M3 × 5mm countersunk and 4 M3 × 5mm pan head) (for PCB mounting)
2 M3 × 6mm pan head screws (for REG1 and REG2)
2 M3 nuts (for REG1 and REG2)
12 PC stakes
1 200mm length of red 10mm diameter heatshrink tubing
2m (or more) of double-sheathed 2-core cable (for kill switch cable from charger to generator)

Semiconductors

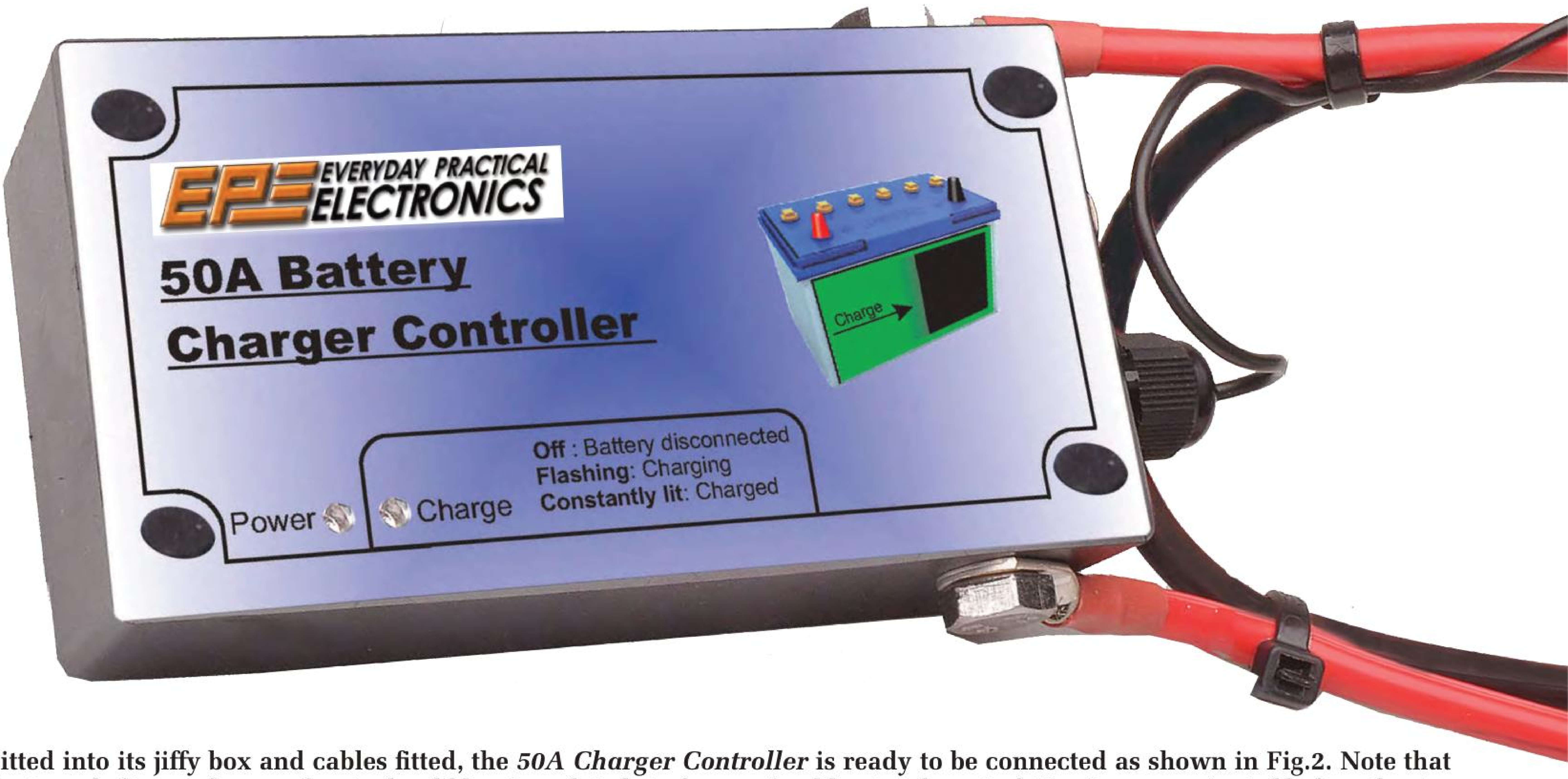
1 PIC12F675-I/P microcontroller programmed with 1111116A.hex (IC1)
1 LM317T adjustable regulator (REG1)
1 LM2940CT-12 low dropout 12V regulator (REG2)
2 BC337 NPN transistors (Q1,Q2)
1 39V 1W zener diode (ZD1)
4 1N4004 1A diodes (D1-D4)
1 3mm red LED (LED1)
1 3mm green LED (LED2)

Capacitors

1 470μF 50V PC electrolytic
3 10μF 16V PC electrolytic
1 470nF 63V or 100V MKT polyester (code 473)
2 100nF MKT polyester (code 103)

Resistors (0.5W, 1%)

1 240kΩ 1 100kΩ 2 22kΩ 1 10kΩ 2 9.1kΩ
4 1kΩ 1 300Ω 1 220Ω 1 120Ω 1 100Ω 1W
1 100Ω multi-turn top adjust trimpot (VR1)
1 5kΩ multi-turn top adjust trimpot (VR2)


EVERYDAY PRACTICAL ELECTRONICS
50A Battery Charger Controller
Charge
Off : Battery disconnected
Flashing: Charging
Constantly lit: Charged
Power
Charge

Fitted into its jiffy box and cables fitted, the *50A Charger Controller* is ready to be connected as shown in Fig.2. Note that the 8mm bolts, washers and nuts should be zinc-plated steel or preferably, stainless steel. Don't use passivated bolts – they're usually not good conductors.

Modifying your generator for a controlled kill!

As explained in the text, one of the best features of this *50A Charger Controller* is that it will automatically turn your generator off when charging is complete.

But to do this, a small 'mod' is necessary – you need to parallel the generator's 'kill' switch with a two-wire cable back to the *50A Charger Controller* 'kill' relay (RLY2).

Exactly how you do this depends to a large extent on your generator. Basically, you need to find space on the control panel to mount a two-pin socket – its mating plug carries the 'kill' command from the *50A Charger Controller*.

Five seconds after the charge is completed, it shorts out the kill switch for five seconds (to ensure the generator really does turn off!).

We modified a Powertech 1kW AC/DC generator which we obtained from Jaycar Electronics some time ago. Unfortunately, this model is not stocked any more – but the basic arrangement is the same for most small generators.

All you need do is find somewhere on the panel to mount the socket so that it doesn't foul anything inside when the panel is replaced on the generator.

We used two-pin microphone sockets on both the *50A Charger Controller* and the generator. They're about the smallest we could find but the big advantage is they have captive (screw-in) plugs and so ensure a reliable connection.

It's then simply a matter of soldering on a short length of two-wire cable from the socket to the terminals on the kill switch (which may be labelled as 'ENG SW' or similar), making sure that the kill switch operation is not disturbed.

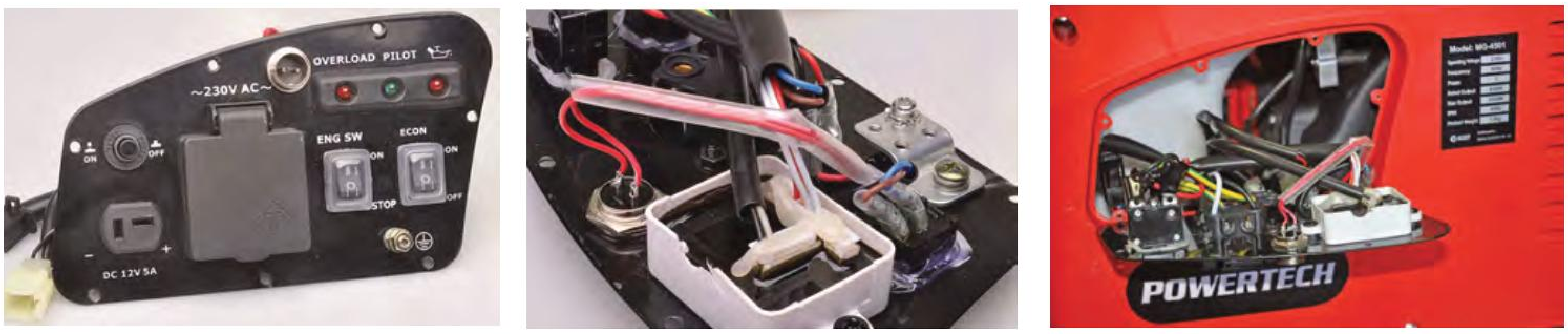
Make up a cable as long as is required with mating plugs and you're ready to rock and roll . . . in silence!

Building it in

These days, most RVs or caravans have a separate 'battery box', more often than not accessible from outside. Unless yours is really crammed full of batteries, it seems like a good idea to mount the charger/controller inside the same box.

Whatever you do, make sure the mounting is solid – you don't want the unit shaking loose halfway up a mountain track! An extra strap around the box would be a worthy 'belts and braces' approach.

Naturally, you'd run the generator outside the van (watch those carbon monoxide fumes!) but connecting cables could stay readily accessible in the battery box.



The modified control panel of the Powertech (Jaycar) 1kW Generator. At left is the two-pin microphone socket we added (about the only spot possible!). Centre is a close-up of the wiring and right is the panel about to go back in.

Win one of two Microchip MCP6N16 Evaluation Boards

EVERYDAY PRACTICAL ELECTRONICS is offering its readers the chance to win a Microchip MCP6N16 Evaluation Board (ADM00640). The MCP6N16 evaluation board is designed to provide an easy and flexible platform when evaluating the performance of the MCP6N16, a zero-drift instrumentation amplifier designed for low-voltage operation and featuring rail-to-rail input and output performance.

The evaluation board is populated with the MCP6N16-100, which is optimised for gains of 100V/V or higher. If one of the other gain option models is desired (eg, MCP6N16-001 for gain of ≥1V/V, or the MCP6N16-010 for gain of ≥10V/V), exchanging the DUT and adjusting the gain-setting resistors can easily be accomplished with standard soldering tools.

The fully assembled evaluation board includes differential input filtering, two jumper-selectable gain settings and output filtering, in addition to an external voltage reference circuit to allow for an adjustable output common-mode level shifting.

The MCP6N16 instrumentation amp is ideal for applications that require a combination of high performance and precision, low power consumption, and low-voltage operation. Examples include sensor interfaces, signal conditioning, and stationary and portable instrumentation for the medical, consumer and industrial markets.

The MCP6N16's low-power CMOS process technology enables low power consumption while still providing 500kHz bandwidth, and it features a hardware-enable pin for even more power savings. This low-power operation and shutdown capability requires less current for the given speed and performance, which extends battery life and leads to less self-heating. In addition, the amplifier's low 1.8V operation allows two dry-cell 1.5V batteries to be drained well beyond typical use, and its rail-to-rail input and output operation enables full-range use, even in low-supply conditions. This provides better performance across the entire operating-voltage range.

WORTH
$60.00
(approx. £45.00)
EACH
MICROCHIP
MCP6N16 Evaluation Board
ADM00640

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CLOSING DATE

The closing date for this offer is 30 November 2017.

July 2017 ISSUE WINNER

Mr Leslie Ratcliffe from Port St Mary, Isle of Man

He won a Microchip PICDEM Lab II Development Platform, valued at £100.00

RAILWAY CROSSING
4
TRACKS
STOP

MICROPOWER LED FLASHER

We've used flashing LEDs for decades – but alas, the LM3909 flashing LED IC is no longer available. What to do?

By JOHN CLARKE

Now we know that that there are lots of LED flashers available and that you can also obtain LEDs with inbuilt flashing. But we still get regular requests for an LED flasher to provide similar functions to the now-obsolete National Semiconductor LM3909 flasher/oscillator.

This new module provides similar functions to the LM3909 but also includes daylight detection with an LDR (light-dependent resistor). Since the LM3909 is no longer available, we have employed a low-cost microcontroller and it drives the LED in a similar way to the National Semiconductor device.

To be specific, it charges a capacitor, then 'jacks it up' and dumps the charge through the LED to give a much brighter flash than would be possible with the otherwise-limited supply voltage. In fact, you cannot normally drive a blue or white LED reliably with a 3V supply – you need to boost the voltage.

By the way, this module does not have to be battery powered. You can run it from any fixed supply from 3 to 5V, so you can eliminate the button cell and just connect it to any 5V USB source. Alternatively, you can run it from a much higher DC voltage if you connect a suitable resistor in series with the input.

Features and specifications

- Flashes any colour LED
- Flash rate set by resistor and capacitor values
- Optional LDR to disable flash with high ambient light
- Two PCB versions to suit different applications
- Small and easy to build
- Supply voltage range: 3-5.5V or higher with modifications (see text)
- Fixed flash time: 65ms
- Standby current: 10μA @ 5V, 2μA @ 3V
- Operating current: typically 0.7-1.6mA (0.5-2Hz) (see Table 1)

Circuit details

The circuit is shown in Fig.1 and uses a PIC12F675 microcontroller, two diodes and several resistors and capacitors. It runs from a lithium button cell, or you could run it from two alkaline AAA cells or a 5V USB supply.

LDR1 is used to detect whether the *LED Flasher* is in daylight or in darkness. This is connected in series with a 470kΩ resistor. In darkness, the LDR resistance is typically well over 1MΩ. When the GP4 output is high (ie, at the positive supply voltage), the 470kΩ resistor pulls the GP2 input sufficiently high for IC1 to detect this as a high level. In daylight, the resistance of LDR1 is around 10kΩ and so GP2's input is held near to 0V. IC1 detects this as a low and then goes to sleep to conserve power.

If the GP2 input is high, indicating that the module is in darkness, the micro provides the LED flasher function, which we will come to in a moment. If the LDR is omitted, this input will always be high and so the flasher will run as long as it has power.

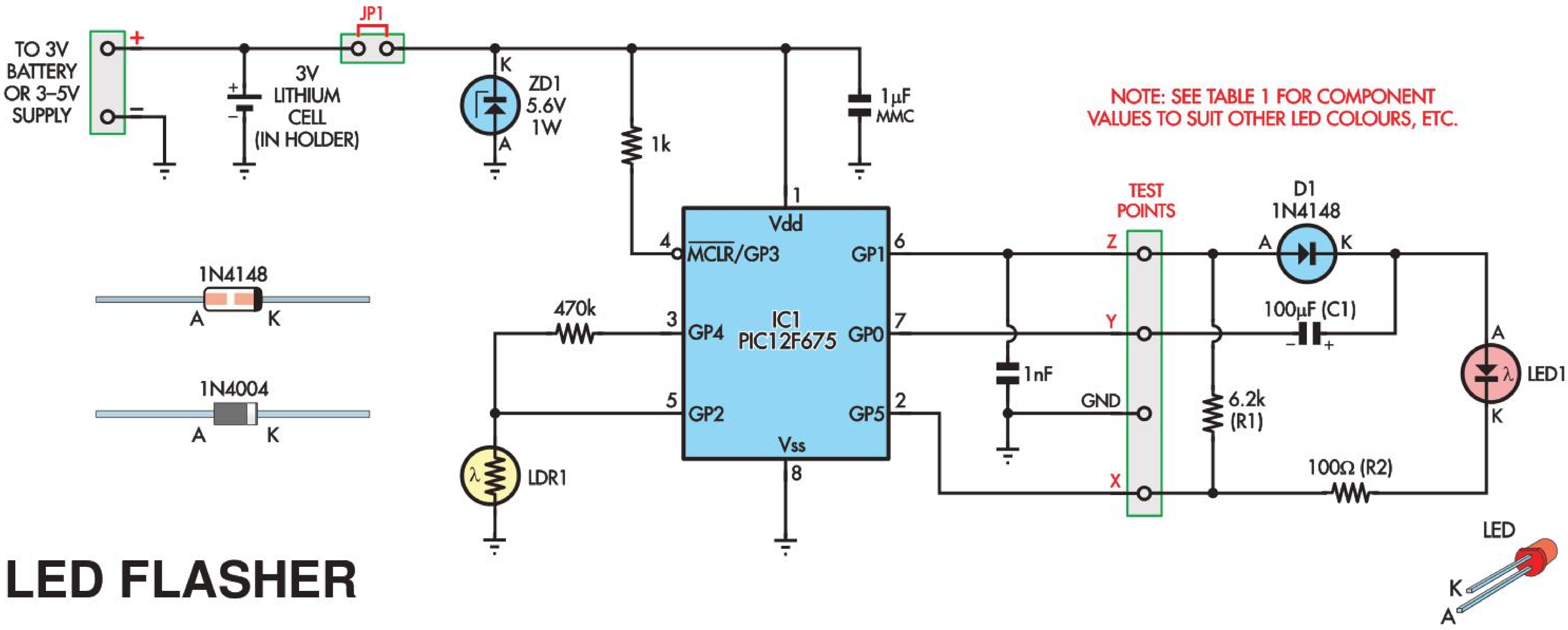
The micro has an internal 'watchdog' timer and this is used to wake it up every 2.3 seconds so that it can check the voltage level at the GP2 input pin. If it is low, the microcontroller goes back into sleep mode. If it is high, LED flashing is enabled.

The flasher section of the circuit comprises diode D1, capacitor C1, resistors R1 and R2, and LED1. We show its operation in Fig.2, which depicts the two modes of the circuit: charging the capacitor and then jacking it up while dumping its charge through the LED.

In the first part of the cycle, the GP5 output (pin 2) is taken high while the GP0 output (pin 7) is held low. In this state, capacitor C1 charges via R1 (6.2kΩ) and diode D1. The charge current path is shown in Fig.2 in green. No current flows through the LED and R2 because this process reverse-biases the LED, as its cathode terminal (labelled K) is held high while the capacitor is charging.

During this process, the voltage across C1 is monitored by input pin GP1 (pin 6). The software compensates for the fact that the voltage at this pin is higher than that at the capacitor's positive terminal due to the forward voltage drop of diode D1.

Once the capacitor has charged to the maximum possible level of about 2.2V, the comparator senses this and switches the GP5 output (pin 2) low and the GP0 output (pin 7) high (up towards +3V). This has the effect of 'jacking up' the negative side of the charged capacitor by about 2.6V or so, which means that the positive terminal will be at around 5V. This is fed to the LED to give a brief


TO 3V BATTERY OR 3–5V SUPPLY
+
–
3V LITHIUM CELL (IN HOLDER)
JP1
K
ZD1 5.6V 1W
A
1k
1µF MMC
NOTE: SEE TABLE 1 FOR COMPONENT VALUES TO SUIT OTHER LED COLOURS, ETC.
1
Vdd
4
MCLR/GP3
GP1
6
470k
3
GP4
IC1 PIC12F675
GP0
7
5
GP2
GP5
2
Vss
8
LDR1
TEST POINTS
Z
Y
GND
X
1nF
D1 1N4148
A
K
100µF (C1)
6.2k (R1)
100Ω (R2)
A
LED1
K
1N4148
A
K
1N4004
A
K
LED
K
A

LED FLASHER

Fig.1: complete circuit for the *LED Flasher*. IC1 charges capacitor C1 via pins 2 and 7 and diode D1. C1 is then discharged through LED1 and R2, with a total flash voltage of about 5V when the circuit is powered from a 3V button cell. This is sufficient to allow blue or white LEDs to be used.

and very bright flash. The LED current path is shown in red in Fig.2.

The cycle then restarts, with GP5 and GP0 swapping polarity, so that capacitor C1 can charge up again.

Since the timing of this cycle is controlled by the component values, the flash rate is set mainly by the values of C1 and R1, but to a lesser extent, the type of LED and the supply voltage.

Table 1 shows typical flash rates and the corresponding component values required for various different LED types. Note that green LEDs require values which are somewhere between those specified for red and blue (depending on the exact construction).

To further demonstrate how this process works, see the scope grab, Fig.3, which shows four traces. The top blue trace is the voltage at GP0, pin 7, which is zero most of the time and switches high for about 65ms (milliseconds). The green trace below is the voltage at GP5, pin 2, which is high most of the time and then drops low during the same 65ms period. The yellow trace shows the voltage at the positive side of capacitor C1.

As you can see, each time GP5 (green trace) goes high, the capacitor voltage starts to ramp up and after slightly less than one second, when GP5 goes low (stopping the charge) and GP0 flicks high, the capacitor voltage takes a sudden jump up. The capacitor voltage then drops over a period of 65ms as it discharges through the LED and the cycle repeats.

The mauve trace is the difference between the voltages at the positive terminal of the capacitor (yellow) and GP5 (green) and it shows a maximum value of 3.6V. This is the effective peak voltage applied to the LED and current-limiting resistor R2.

Referring back to Table 1, note that the peak current is higher with a lower voltage drop LED (eg, red) compared to a higher voltage drop LED (blue or white). Also be aware that electrolytic capacitors typically have a wide tolerance range of –20% to +100%, so the flash rate may vary from the calculated rate, depending on the actual capacitance.

Flash brightness can be increased by reducing the value of R2 or using a larger capacitor (up to 470µF) and scaling down R1's value proportionally. The minimum recommended value for R2 is 100Ω. For example, to flash a blue LED at 1Hz, you could increase C1 to 220µF and reduce R1 to 33kΩ and this will roughly double the LED current (as well as increasing the supply current drawn).

Note that the flash rate is inversely proportional to the supply voltage and is about 50% faster at 2V and 22% slower at 5V, compared to 3V.

Zener diode ZD1, across IC1's supply, protects IC1 from reverse supply polarity, as it will be forward-biased under this condition. Its typical leakage current during normal operation with a 3V cell is around 10nA. JP1 functions as an off/switch.

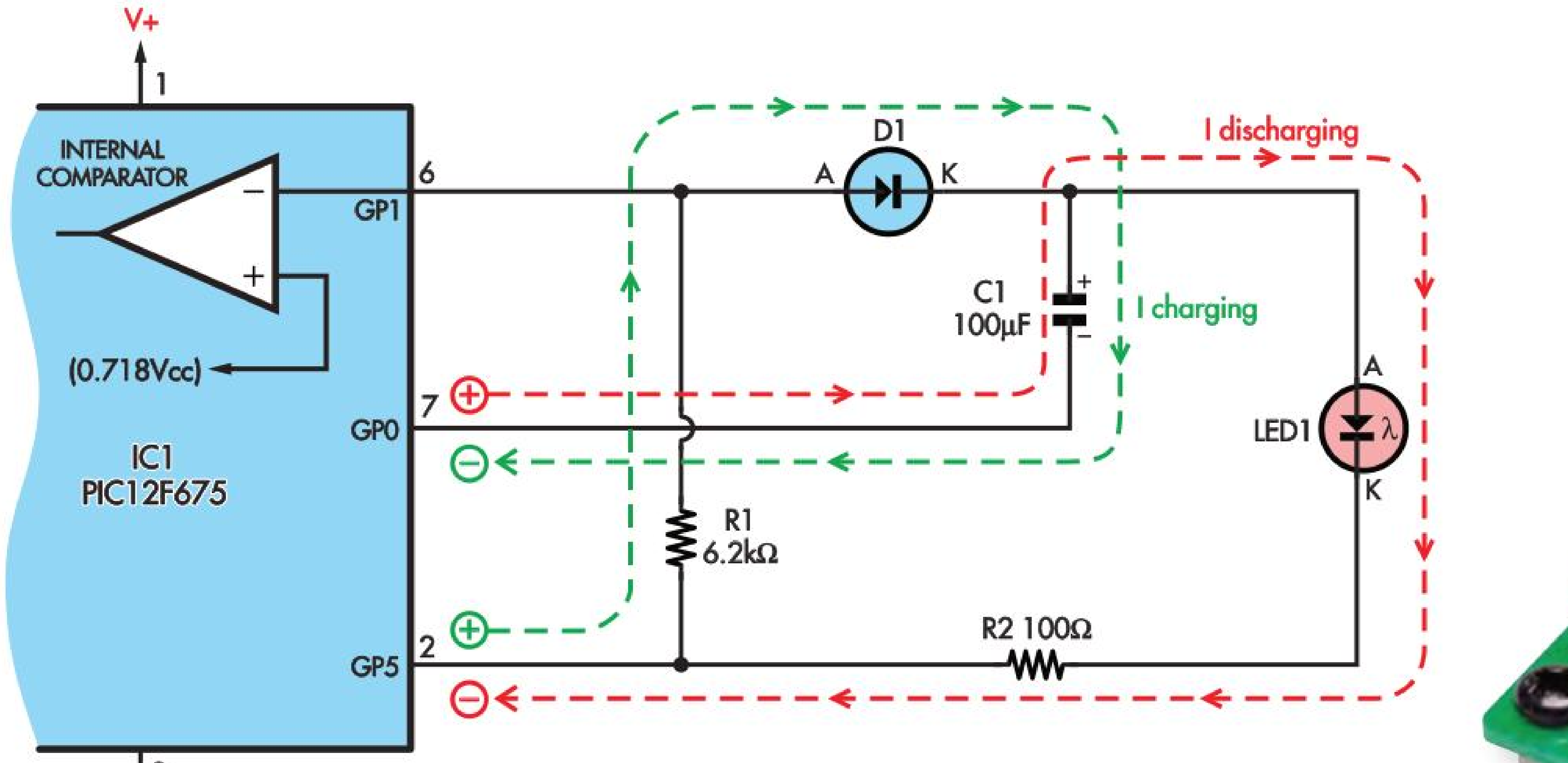

V+
1
INTERNAL COMPARATOR
–
+
GP1
6
(0.718Vcc)
IC1 PIC12F675
7
GP0
2
GP5
8
D1
A
K
I discharging
C1 100µF
+
I charging
A
LED1
K
R1 6.2kΩ
R2 100Ω

Fig.2: the charge and discharge currents for timing/boost capacitor C1. The charge-current path is shown in green while the discharge-current path is shown in red. Output pins 2 and 7 reverse polarity to switch current flow between the two paths, while pin 6 monitors C1's charge status to determine when to switch between charging and discharging.

3V CELL 1
LDR1
LED1
LED FLASHER
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1N4004
1nF
1µF
D1
D2
1N4148

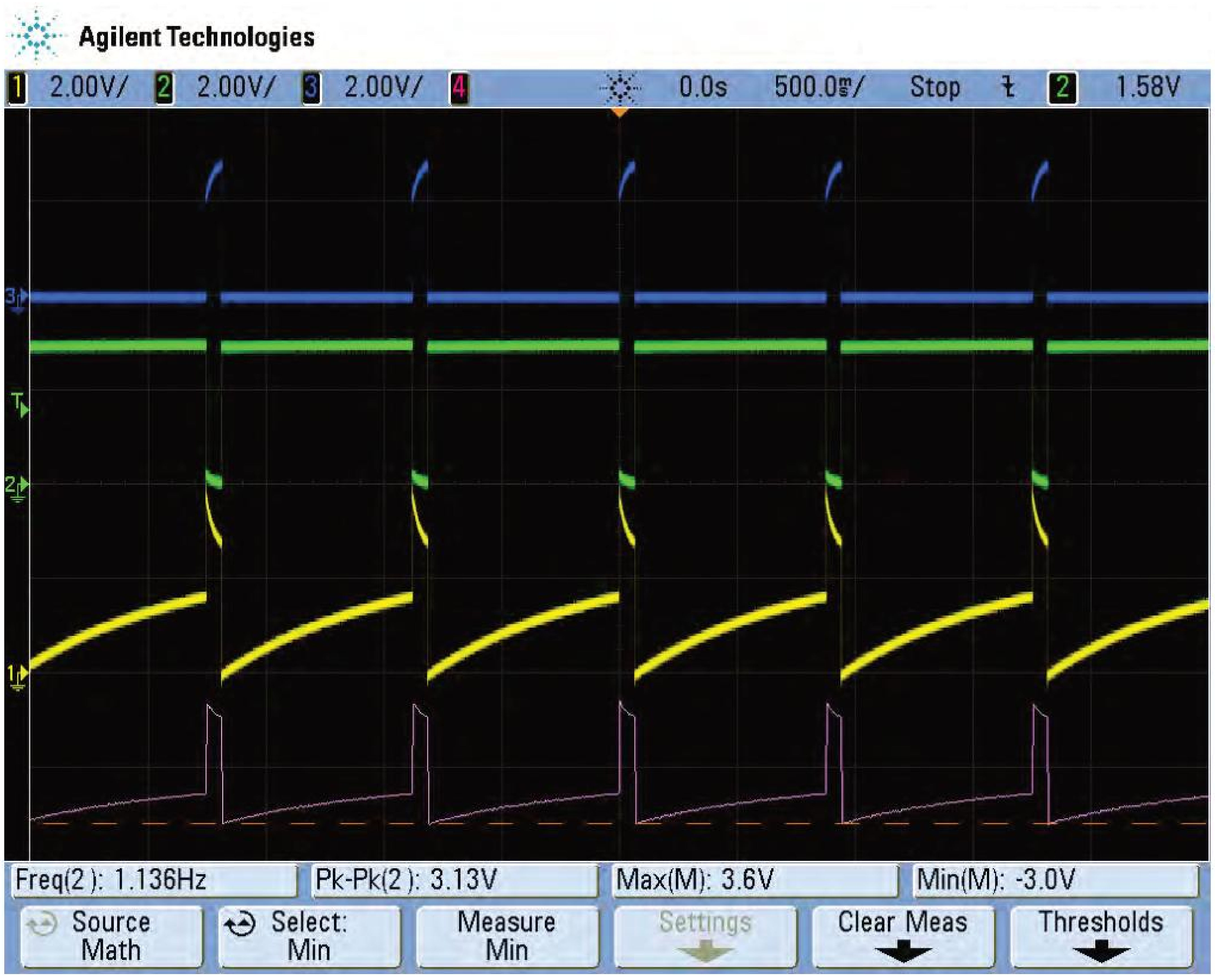

Fig.3: scope grab showing the critical voltages. The blue trace is pin 7 (GP0); the green trace is pin 2 (GP5); the yellow trace is the positive terminal of capacitor C1, while the mauve trace is the voltage across LED1 and R2. This shows a peak value of 3.6V, despite the 3V supply.

ZD1 also provides protection against over-voltage to the microcontroller and it limits the supply to around 5.5V if you are using a much higher DC input voltage together with a series dropping resistor. In that case, the dropping resistor could be installed on the PCB in the place of JP1 (see 'Higher supply voltages'). But we are getting a little ahead of ourselves.

PCB assembly

The *LED Flasher* is constructed on a PCB which is available from the *EPE PCB Service*, coded 16109161, measuring 45 × 47mm. If you wish, the PCB can be clipped into a small UB5 case (83 × 54 × 31mm), although most constructors probably will not bother.

Before you assemble the PCB, you need to select the components required for R1, R2, C1 and the LED colour, eg, red, yellow, blue or white. Table 1 shows typical component values.

Fig.4 shows the PCB overlay. Begin construction by installing the resistors, using a multimeter to check the value of each before inserting it into the PCB.

Diodes D1 and ZD1 can now be installed, taking care to orient these correctly. The socket for IC1 is then fitted, with the notch towards the top of the board. Install the capacitors, and if you are using a polarised electrolytic for C1, then this must be fitted with the shown polarity, ie, the longer lead inserted through the pad towards the top of the board.

Then solder in the 2-way pin header for JP1. The 4-way header is optional; it provides convenient test points if you want to check the module's operation or display the various waveforms on a scope.

Install the cell holder, if using the 3V lithium cell as the supply. The positive side of the holder must be oriented as shown, to the top of the PCB.

If you are not going to use the cell holder, you can install two PC stakes for supply connections instead. Note that there are two 3mm-diameter holes in the PCB located where the cell holder would otherwise sit. These are for looping the connecting wires through for stress relief. That's so the wires do not break off where they connect to the power PC stakes.

Alternatively, you can elect to install an SMD mini-USB type B socket on the underside of the PCB (ie, instead of installing the cell holder) for convenient connection to a USB source.

LED1 is mounted with the anode 'A' oriented as shown and LDR1 can be installed now as well. Note that if you do not want the circuit to switch off in the day, omit LDR1.

If required, the PCB can be fitted with four 9mm tapped spacers at each corner of the PCB, attached with short M3 machine screws.

If you intend to program the PIC yourself, the firmware file (1610916A.HEX) can be downloaded from the *EPE* website.

Powering it up

Insert IC1 into the socket, making sure it is oriented correctly. Watch out that you don't bend any pins under the IC. Now install the CR2032 cell in its holder (or apply 3-5V DC) and place the jumper link onto the 2-way header (JPI). If all is well, LED1 will begin to flash.

Version 2: a tiny PCB

For some applications, where you want a tiny flasher module, the PCB with its on-board cell holder will be too large. For example, you might want to install the LED flasher inside an HO/OO-gauge

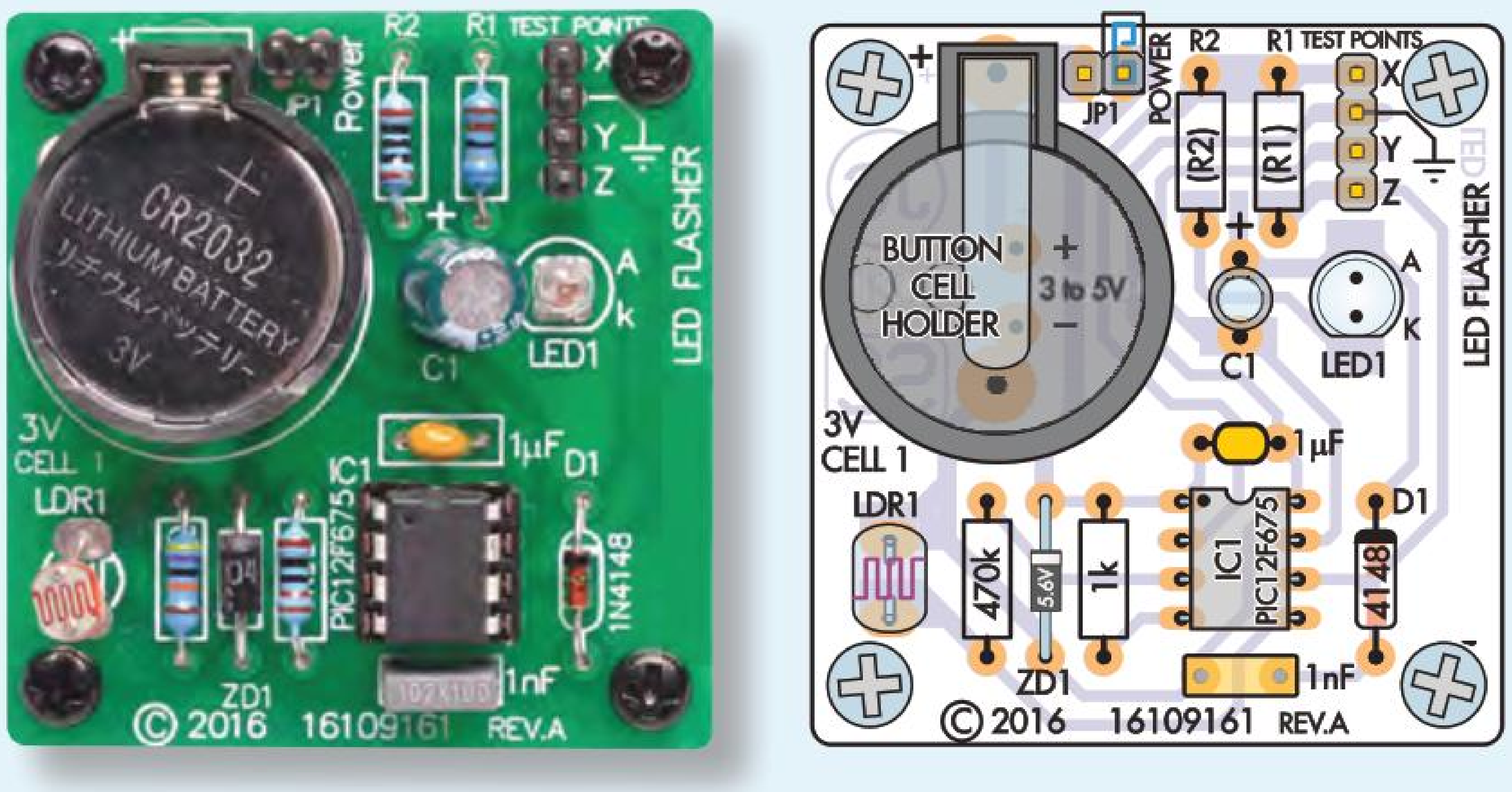

Fig.4 (left): the larger of the two *LED Flasher* boards. Use this as a guide during assembly and take care with the polarity of IC1, C1, D1 and ZD1.

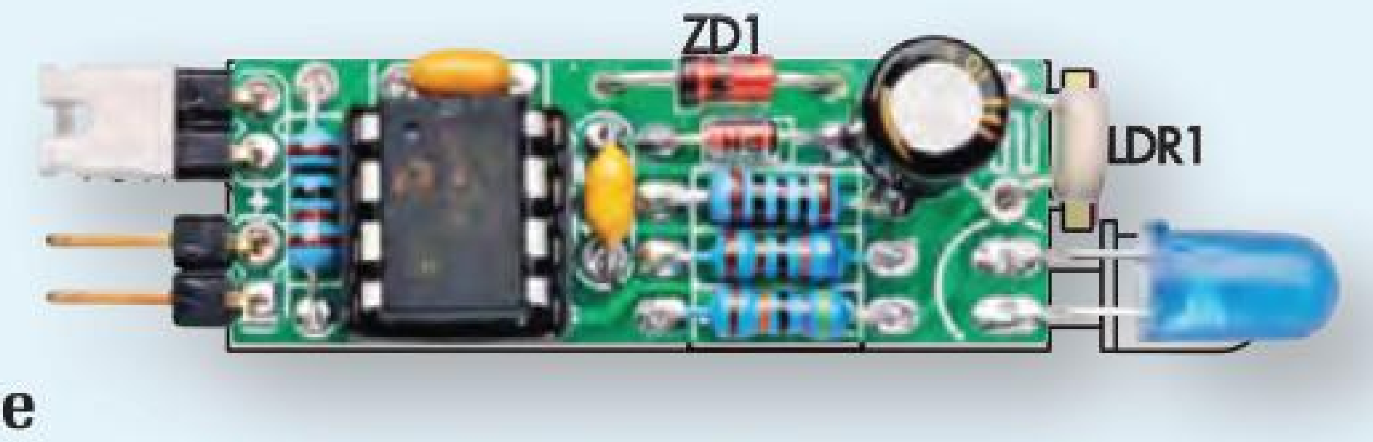

Fig.5 (right): fit the components to the smaller *LED Flasher* board in this manner. Taller passive components such as C1 can be fitted to the bottom of the board and laid over to save space.

Table 1: LED Flasher component selection for 3V supply

LED colour	Supply current @3V supply	Peak LED flash current	C1	R1	R2	Flash rate
Blue/white	680µA	3.6mA	100µF	15kΩ	330Ω	0.5Hz
Blue/white	760µA	3.6mA	100µF	10kΩ	330Ω	0.75Hz
Blue/white	830µA	3.6mA	100µF	7.5kΩ	330Ω	1Hz
Blue/white	1.0mA	6mA	100µF	7.5kΩ	100Ω	1Hz
Blue/white	1.1mA	3.6mA	100µF	3.9kΩ	330Ω	2Hz
Red/orange/yellow	750µA	6mA	100µF	12kΩ	330Ω	0.5Hz
Red/orange/yellow	860µA	6mA	100µF	8.2kΩ	330Ω	0.75Hz
Red/orange/yellow	950µA	6mA	100µF	6.2kΩ	330Ω	1Hz
Red/orange/yellow	1.1mA	10mA	100µF	6.2kΩ	100Ω	1Hz
Red/orange/yellow	1.6mA	6mA	100µF	2.7kΩ	330Ω	2Hz

model diesel locomotive, or inside an HO/OO wagon at the end of a train as a BOG (battery-operated guard).

For these other applications, which require a tiny module, we have produced an alternative PCB, also available from the *EPE PCB Service*, which measures only 36 × 13mm and this board is coded 16109162. We could have made it even smaller if we had designed it to use surface-mount devices, but we know that some readers, and particularly model railway enthusiasts, are not keen on soldering SMDs.

The same components are installed on the smaller PCB, except that it does not have provision for the button cell holder or optional 4-way pin header. Refer to Fig.5 when building this version. Note that some components could be installed laid over on their side on the bottom of the PCB, to reduce the overall size of the package (eg, C1).

Higher supply voltages

If you want to run the PCB from more than 5V, you will need to install a suitable dropping resistor across the input link, JP1. For a 12V supply, we suggest a value of 1kΩ with a rating of 1/4W.

If you want to run the tiny module in a model railway locomotive or freight wagon as an end-of-train device, you will need to take account of the track polarity. To do this, use a small bridge rectifier from the track (eg, type W01). Its two AC connections go to the track connections inside the loco or wagon and the DC wires go to the appropriate DC input wires on the PCB.

Furthermore, to provide for operation when the track is not energised, you could substitute a .047F or 1F 5.5V supercap for the 1µF MMC capacitor on the board. You will likely need to connect it via insulated flying leads. In this case, change ZD1 to a 5.1V type to ensure the super-capacitor cannot be charged beyond its 5.5V rating.

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Parts List

1 PCB available from the *EPE PCB Service*, coded 16109161 (45 × 47mm) OR
1 PCB available from the *EPE PCB Service*, coded 16109162 (36 × 13mm)
1 20mm button cell holder**
1 CR2032 Lithium cell** (3V)
1 SMD mini-USB socket* (CON1)
1 10kΩ light-dependent resistor* (LDR1)
1 DIL8 IC socket*
4 M3 × 9mm spacers*
4 M3 × 6mm machine screws*
1 2-way pin header, 2.54mm pitch (JP1)
1 jumper shunt for JP1
1 4-way pin header, 2.54mm pitch*
2 PC stakes*
* optional component
** not fitted to smaller PCB

Semiconductors
1 PIC12F675-I/P programmed with 1610916A.HEX (IC1)
1 1N4148 diode (D1)
1 5.1V or 5.6V zener diode (ZD1) (see text)
1 3mm or 5mm high-brightness LED (LED1)

Capacitors
1 100µF 16V electrolytic capacitor (C1)
1 1µF multi-layer ceramic
1 1nF 63V or 100V MKT polyester

Resistors (0.25W, 1%)
1 470kΩ   1 1kΩ
1 6.2kΩ#   1 330Ω#
# change values to vary flash rate and brightness; see text and Table 1

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OUT
R
IN
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L
R

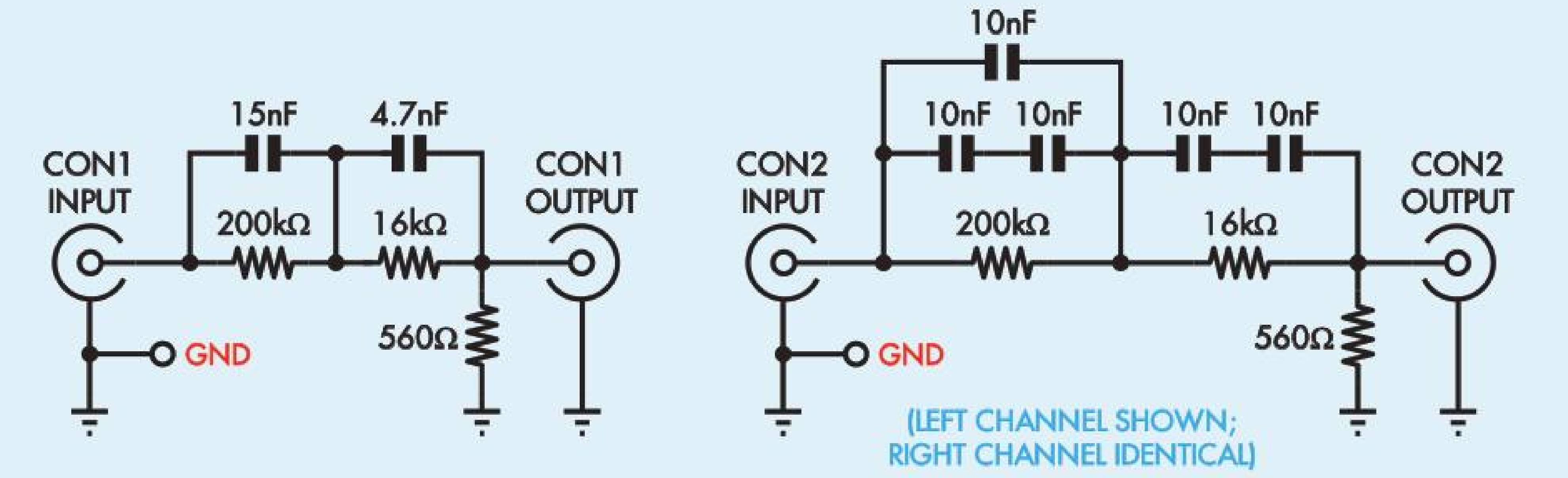
Design: NICHOLAS VINEN
Article: BAO SMITH

This passive converter circuit lets you use the phono inputs on an amplifier or mixer, normally used for a turntable, as a pair of line-level inputs. This lets you plug in another CD player, DVD player or other line-level program source.

WHILE TURNTABLES may be making a slight resurgence over the last few years, they're still a rare sight in most people's homes. Because of this, you often find the phono inputs on the back of an amplifier go unused.

So, what to do if you need another pair of inputs for a CD or DVD player? Our solution is to convert the phono inputs to line inputs via an external adaptor; the original idea being credited to Gary Johnston of Jaycar Electronics.

It's best not to plug a line-level device straight into a phono input for two reasons. One, because they provide approximately 34dB of amplification, which would cause it to overload; and two, the RIAA equalisation that is applied by a preamplifier built into the amplifier.



PHONO INPUT CONVERTER

Fig.1: the circuits for both versions of the *Phono Input Converter*. The left circuit is made with through-hole components, while the right circuit is made with SMD components.

RIAA equalisation applies boost for lower frequencies (up to +20dB at 20Hz), approaching zero at 1kHz. Above 1kHz, the circuit applies treble cut that increases as the frequency rises to 20kHz (the cut being almost 20dB).

In effect, our converter applies the inverse of RIAA equalisation to the signal before passing it to the amplifier, which after applying the normal equalisation, leaves us with a virtually flat frequency response.

Since a typical phono preamplifier applies about 34dB of gain, our passive circuit needs approximately 34dB of attenuation and a filter that is the exact inverse of the RIAA equalisation.

In Fig.2 you can see the RIAA equalisation curve (yellow) and the ideal inverse curve (green). The dotted yellow line shows the RIAA equalisation curve with IEC amendment from 1976. The IEC amendment added a bass turnover at 50Hz, used to reduce very low frequency signals from the turntable. The general slope of the RIAA equalisation curve is 6dB/octave, and there are two inflections at approximately 500Hz and 2kHz.

Now look at Fig.1. There are two versions of the converter circuit; one using conventional through-hole components, while the other uses surface-mount components (SMD). Note that both versions are virtually identical electrically. Both are passive circuits, meaning that no semiconductors or integrated circuits are used, and no power supply is needed.

Circuit details

When designing the circuit, we needed to consider the type of source input it would be used with.

Most program sources, whether CD or DVD players, or an AM/FM tuner use operational amplifiers in their output stages and they have very low output impedances. This means that this passive circuit can have quite a low impedance and not have any adverse effect on the performance of the source signal.

Next, as well as applying signal attenuation, the converter must have a characteristic which is the inverse of the RIAA equalisation curve. As a result, there should be minimal difference between connecting a CD player into line inputs compared to feeding it into phono inputs via this converter.

Hence, the circuit for each channel consists of a 200kΩ resistor shunted by a 15nF capacitor, in series with the combination of a 16kΩ resistor shunted by a 4.7nF capacitor. This describes the through-hole version of the circuit (left side of Fig.1).

Parts List

1 PCB available from the *EPE PCB Service*, coded 01111161, 53 × 40.5mm
1 4-way RCA socket
1 UB5 jiffy box
1 laser-cut lid (optional)
1 panel label to fit lid (optional)

Through-hole version

Capacitors

2 4.7nF MKT polyester, 63/100V
2 15nF MKT polyester, 63/100V

Resistors (1/4W metal film, 1%)

2 560Ω* 2 16kΩ 2 200kΩ

SMD version

Capacitors (SMD 3216/1206)

10 10nF 50V C0G 5%

Resistors (SMD 3216/1206, 1/4W, 1%)

2 560Ω* 2 16kΩ 2 200kΩ

** change values to vary attenuation, see text*

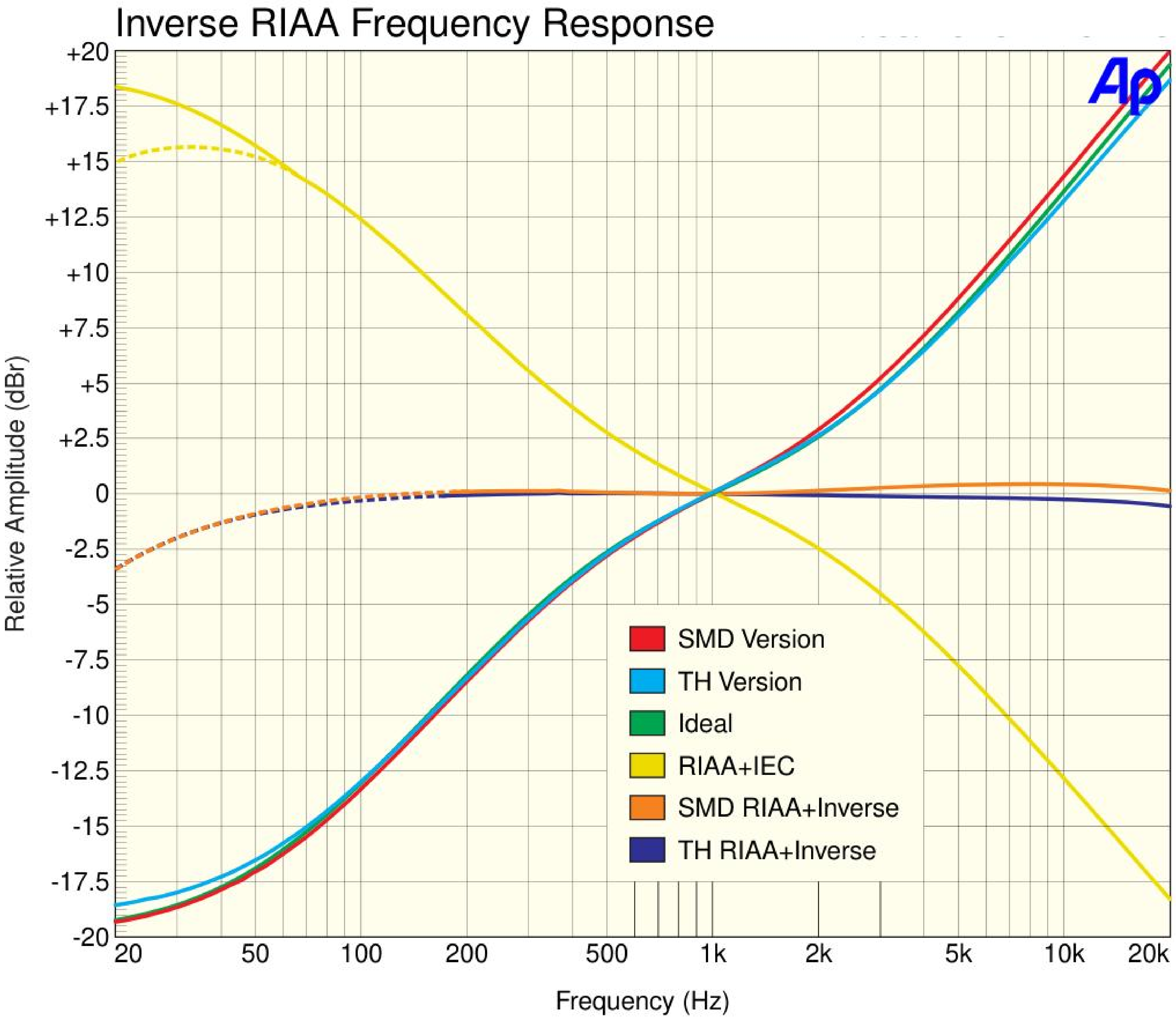


Fig.2: the red and blue line in the centre show the frequency response of the *Phono Input Converter* hooked up to our LP Doctor. For the most part, it is fairly flat until it starts to deviate at 100Hz due to the IEC-amended RIAA equalisation curve, shown in the dotted yellow line.

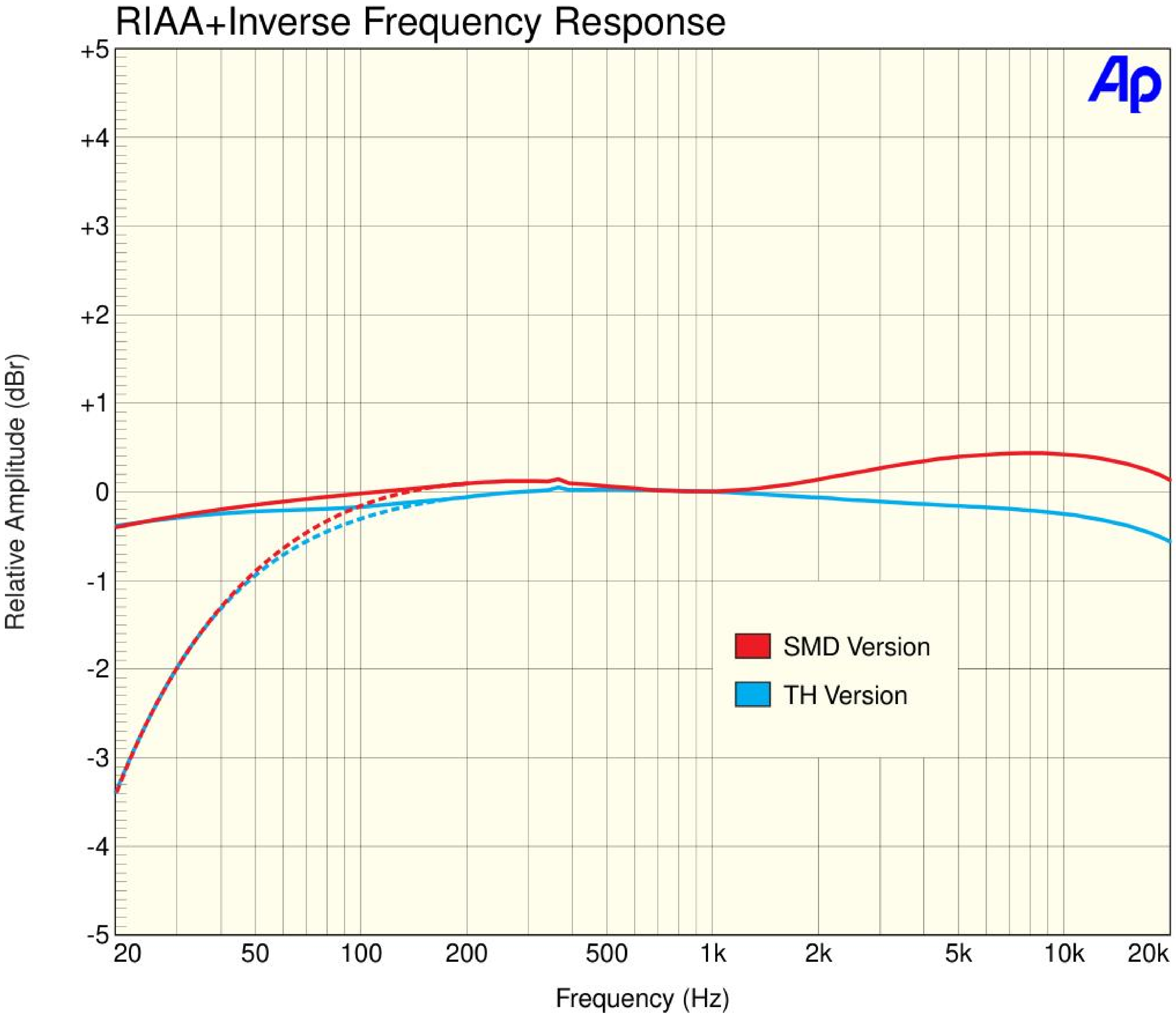


Fig.3: a close-up of both frequency response curves for the SMD and through-hole versions. Variations in the response can occur due to component tolerances and the quality of the amplifier used. Whether your amplifier uses an IEC amended equalisation curve will also affect the response below 50Hz.

The SMD version on the righthand-side of Fig.1 provides nearly the same shunt capacitance but uses series or series-parallel combinations of 10nF capacitors, allowing us to provide capacitance values closer to the ideal inverse RIAA characteristic.

In fact, you can see from Fig.2 that the SMD version is much closer to the RIAA equalisation curve for lower

1=10nF C0G 6=16kΩ
2=200kΩ
5=560Ω
GND
01111161
RevA
Inverse RIAA

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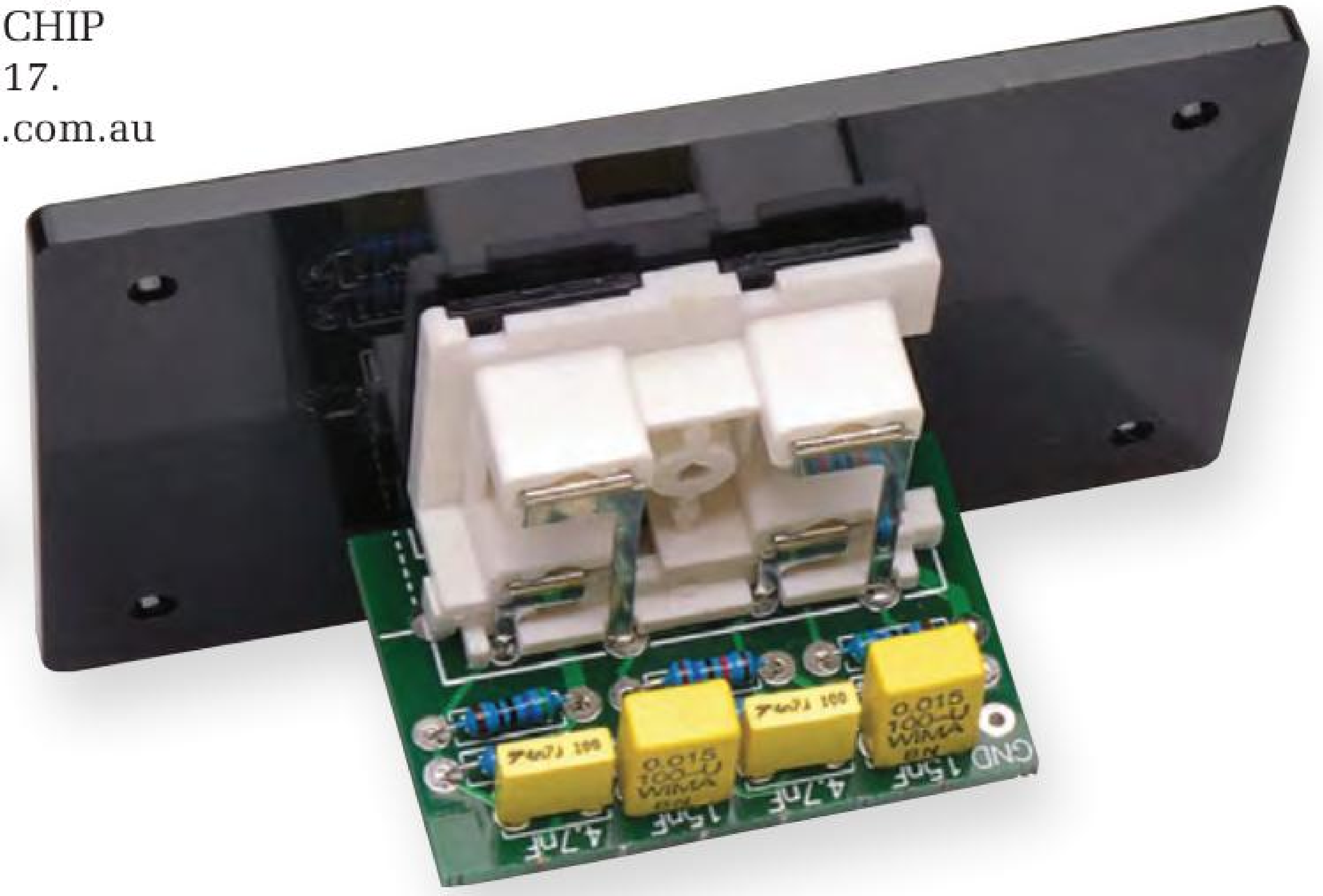

Above, you can see the rear view of the SMD version of the *Phono Input Converter*, while below is the front of the converter with optional label. Right is the rear of the through-hole version.

frequencies, while the through-hole version is closer at higher frequencies. In the end, how accurately you can replicate the curve comes down to the quality of the passive components used.

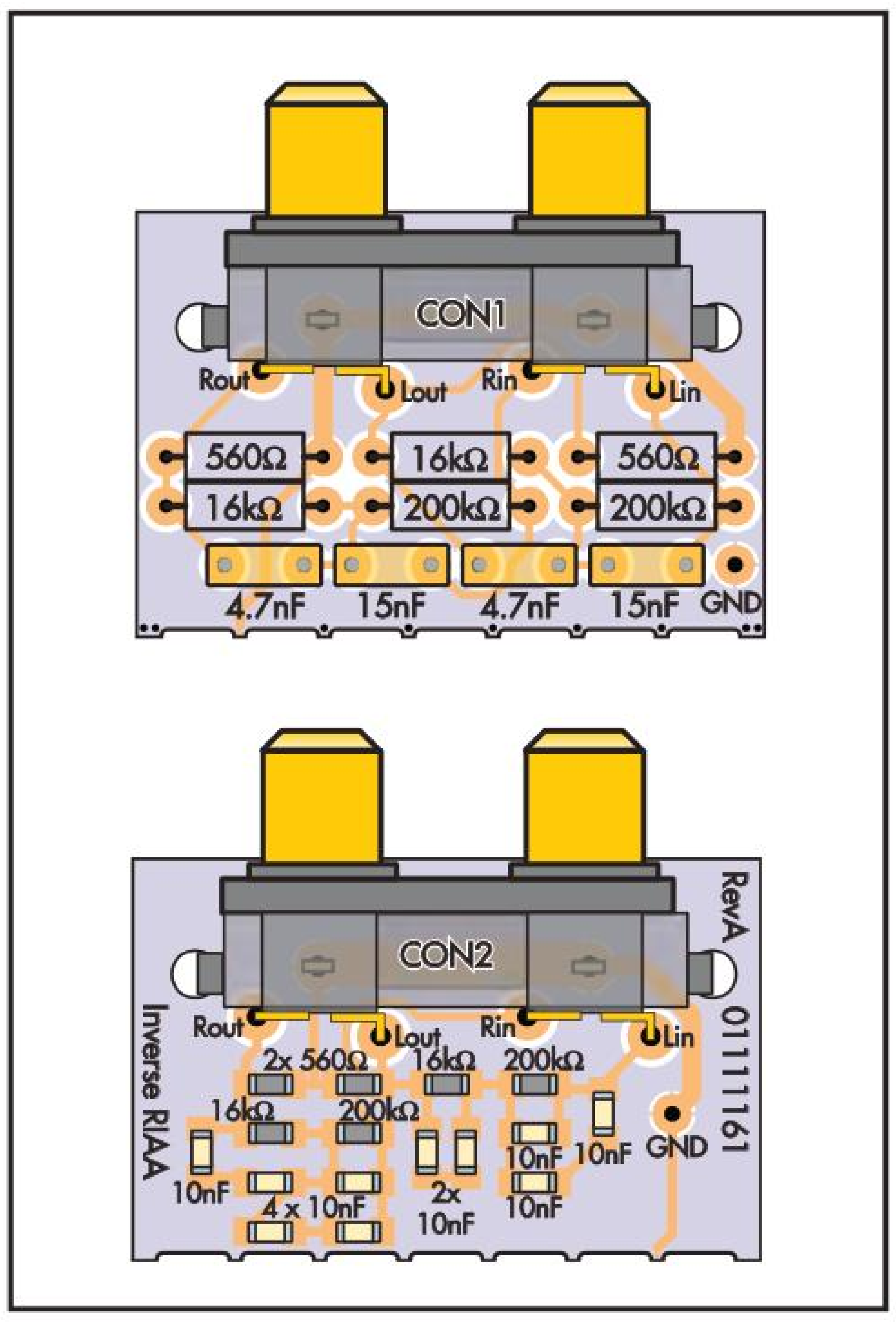

Fig.4: complete PCB overlays for the through-hole (top) and SMD (bottom) versions of the *Phono Input Converter*.

We used C0G SMD capacitors in our converter as they have better tolerance and a more linear response, providing a closer replication of the inverse curve.

Performance

We tested both circuits with the LP Doctor, which incorporates a high-performance RIAA preamplifier.

The superposition of both curves is shown in Fig.3, the dotted lines showing the response with the IEC amended equalisation curve. Both provide an overall frequency response within ±0.5dB from 20Hz to 20kHz.

However, due to the bass turnover, from the IEC amendment, you end up with a slight cut to bass below 50Hz, culminating in about 3.5dB of cut at 20Hz (if your preamplifier applies the IEC amendment). Both circuits had a signal-to-noise ratio of 96dB unweighted with respect to 1kHz using a $2.2V_{RMS}$ input. Which is in the range of what you would expect from your average CD player.

You can build the SMD or through-hole version

The PCB for this project is available from the *EPE PCB Service*, measuring 53 × 40.5mm and coded 01111161, which has both versions for a complete converter. You can build either one, or both if you need two converters. Either way, you will need to break the board in two and populate the one you want with surface-mount or through-hole components.

To house the finished converter, we used a small plastic case from Jaycar. Five holes will need to be drilled in the lid for the four RCA phono sockets and screw to hold the PCB/socket in place, or purchase a laser-cut lid. The laser-cutting diagram and panel label can be downloaded from the *EPE* website.

When using the unit, keep it away from the power transformer in the amplifier and make sure the input and output leads do not run across mains power cords, otherwise hum pickup can become a problem.

Depending on the signal levels from your CD player, or other input source, you may need to increase or decrease the degree of attenuation provided.

You can provide greater attenuation by reducing the 560Ω resistor at the output, eg, using a 330Ω resistor. Alternatively, a 1kΩ resistor will provide less attenuation.

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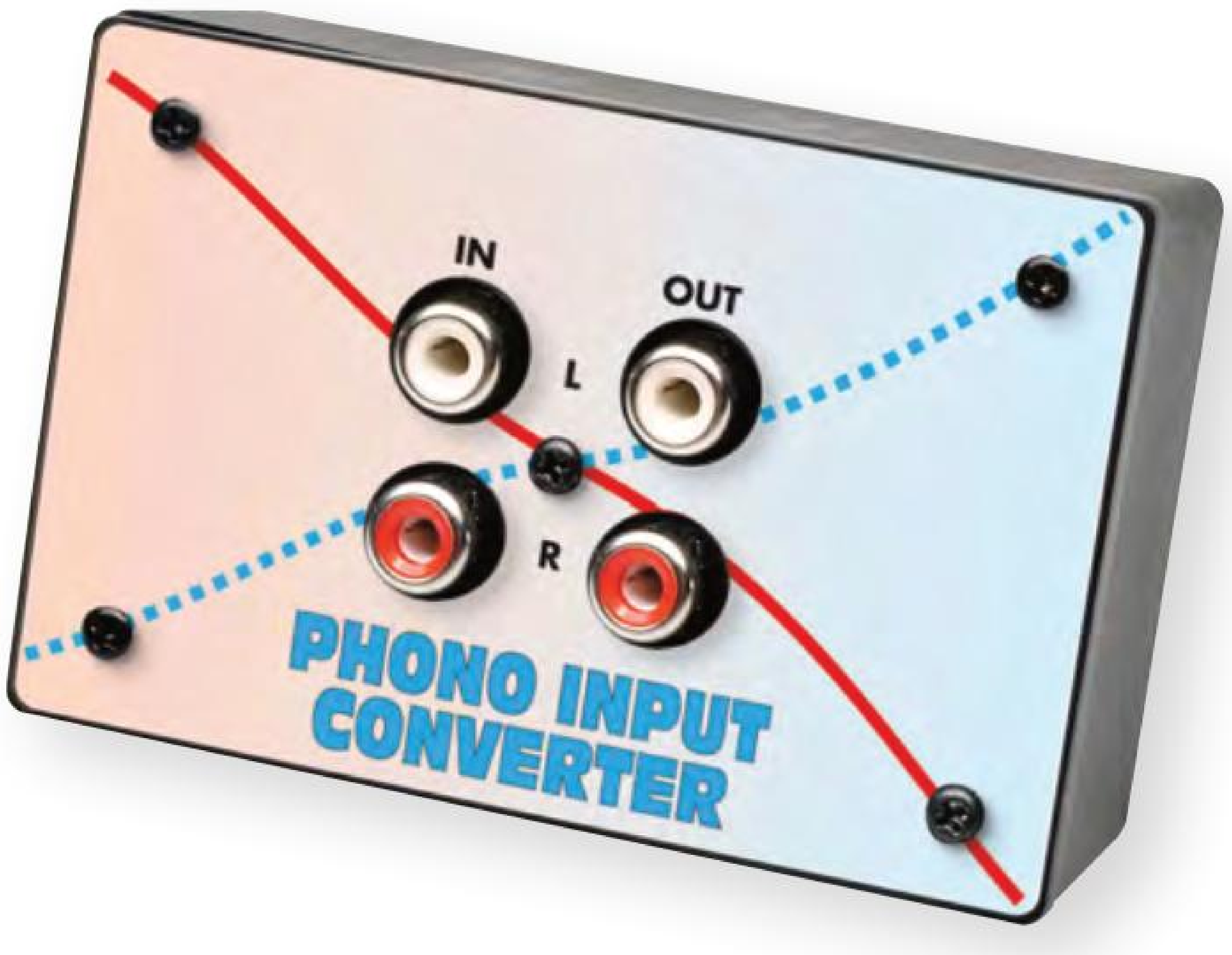

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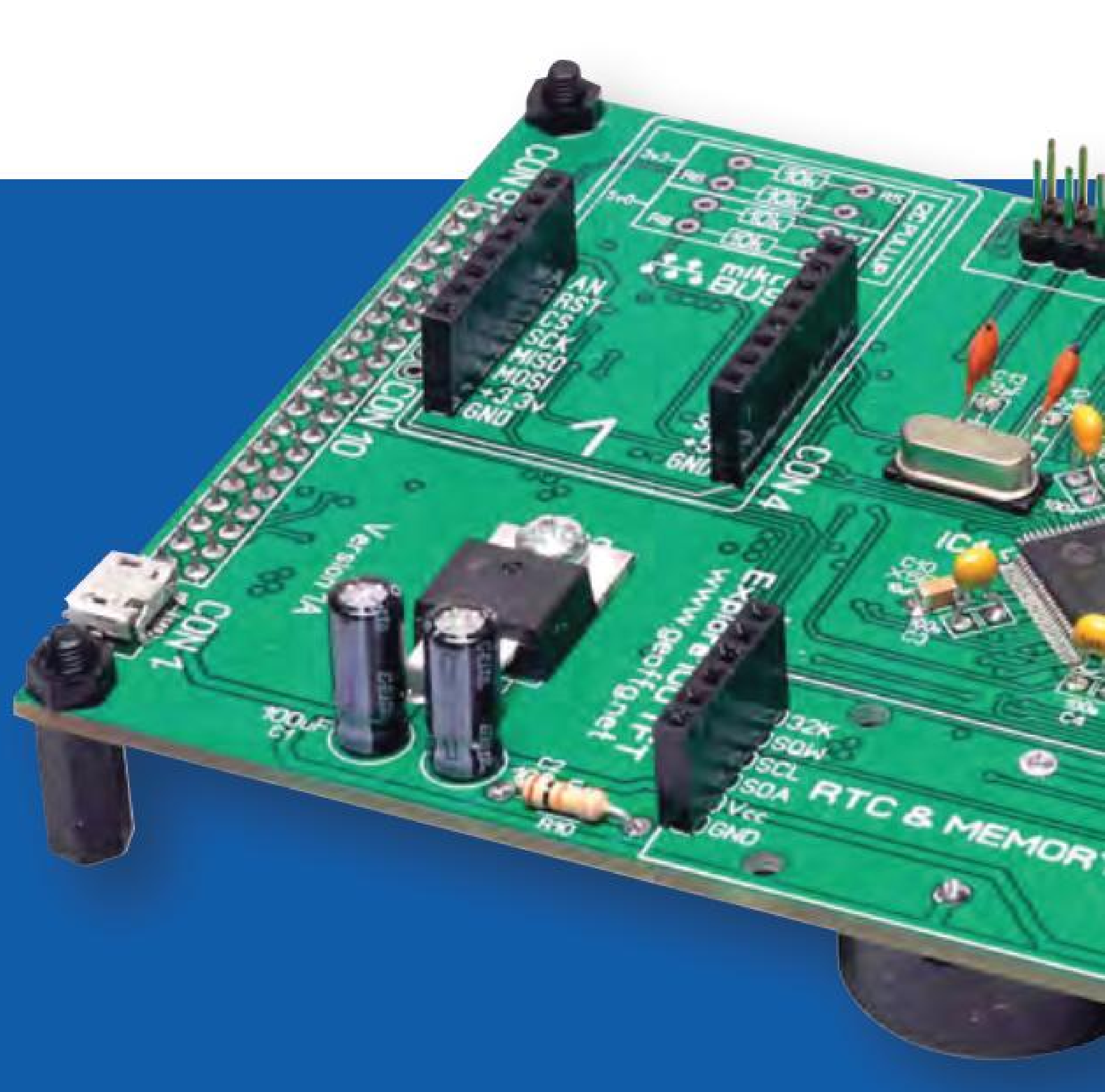
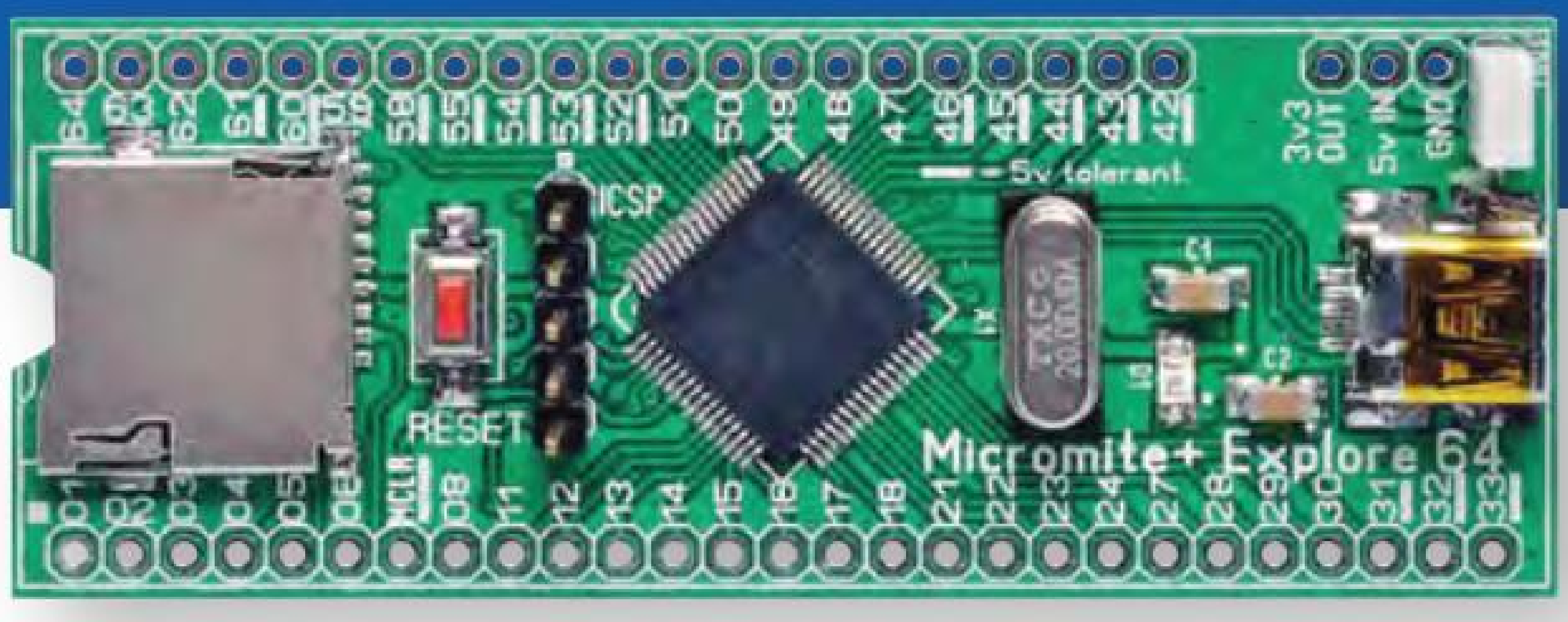
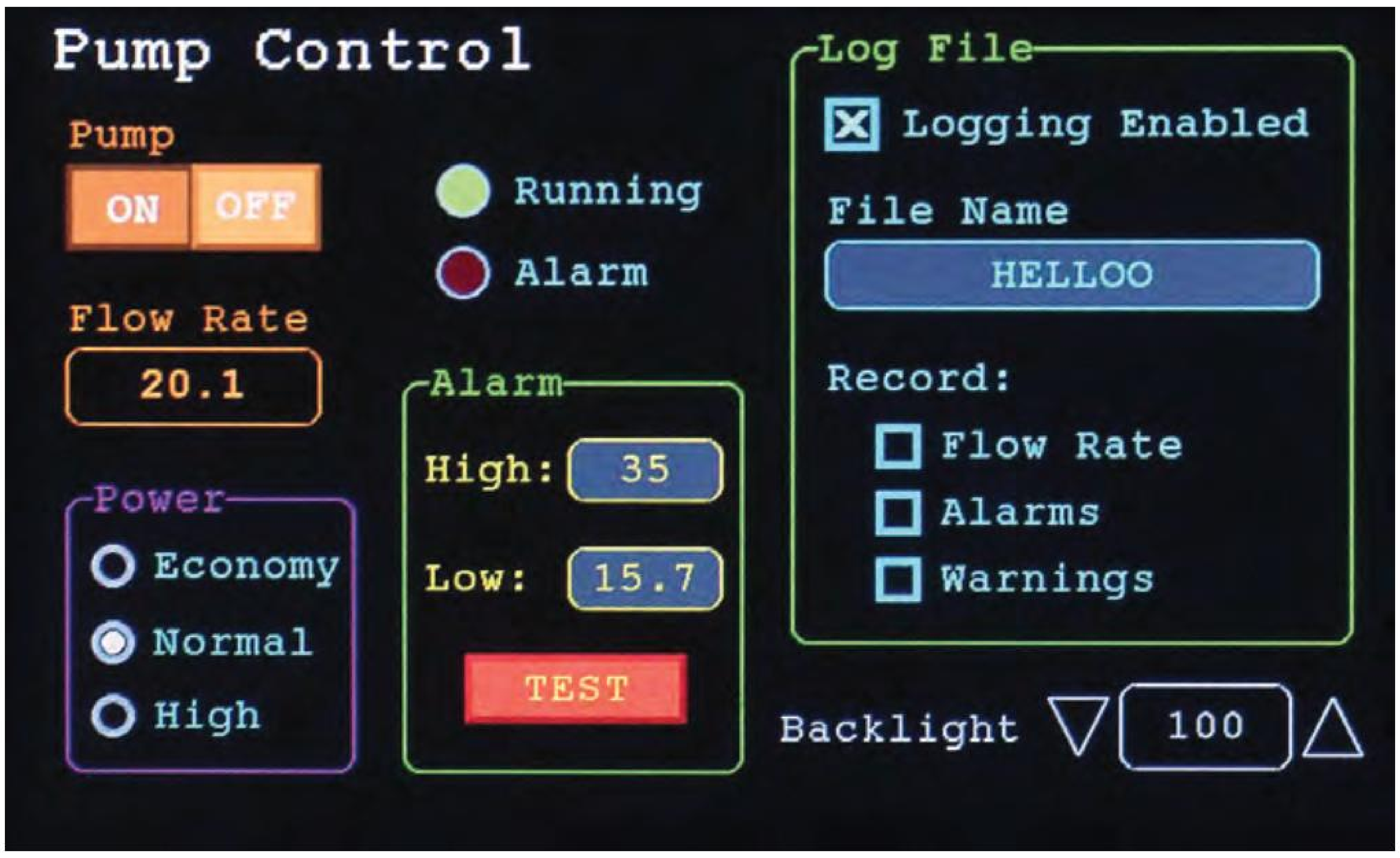


Micromite Plus Advanced Programming

Part 1: By Geoff Graham



The Micromite Plus is not only faster than the Micromite, but also boasts more RAM and storage space. It also has several new and important programming features such as SD card support and a graphical user interface (GUI) application library. This makes it easier than ever to develop an interactive touchscreen control panel; in fact, it will take you hours rather than months!


Pump Control

Pump

ON OFF

● Running

● Alarm

Flow Rate

20.1

Power

○ Economy

● Normal

○ High

Alarm

High: 35

Low: 15.7

TEST

Log File

☒ Logging Enabled

File Name

HELLOO

Record:

☐ Flow Rate

☐ Alarms

☐ Warnings

Backlight ▽ 100 △

Fig.1: this screen shot shows an example of a control panel created by a BASIC program. Each object on the screen was created using a single BASIC command which specified the parameters of the control such as its type, location, dimensions and colour. MMBasic then manages the controls in the background. For example, when a button is pressed, MMBasic will change its appearance accordingly.

THE MICROMITE Plus has a number of new BASIC commands and features compared to the original Micromite, so even experienced Maximite/Micromite/BASIC programmers will have some new things to learn before they can take full advantage of its capabilities. So, having introduced the Explore 64 module in August and the Explore 100 computer in September, it's time to get into the nitty gritty of using these amazing new features.

This month, we'll look at the new SD card file reading and writing support, and also start delving into advanced GUI programming. In Part 2 next month, we'll go over even more advanced techniques to make your GUIs slicker and easier to use, as well as to program.

SD card socket

Both the Explore 64 and Explore 100 boards are equipped with a microSD card socket, which is fully accessible from within a BASIC program. The Explore 100 board can also read and write to full-size SD cards if a display module is attached, which has an on-board SD card socket, or if a socket is wired to pin header CON10.

Regardless of which type of SD card you're using, you can have up to five files open at the same time and you can access or write the data sequentially or via random access. This makes the Micromite Plus perfect for logging data for later analysis.

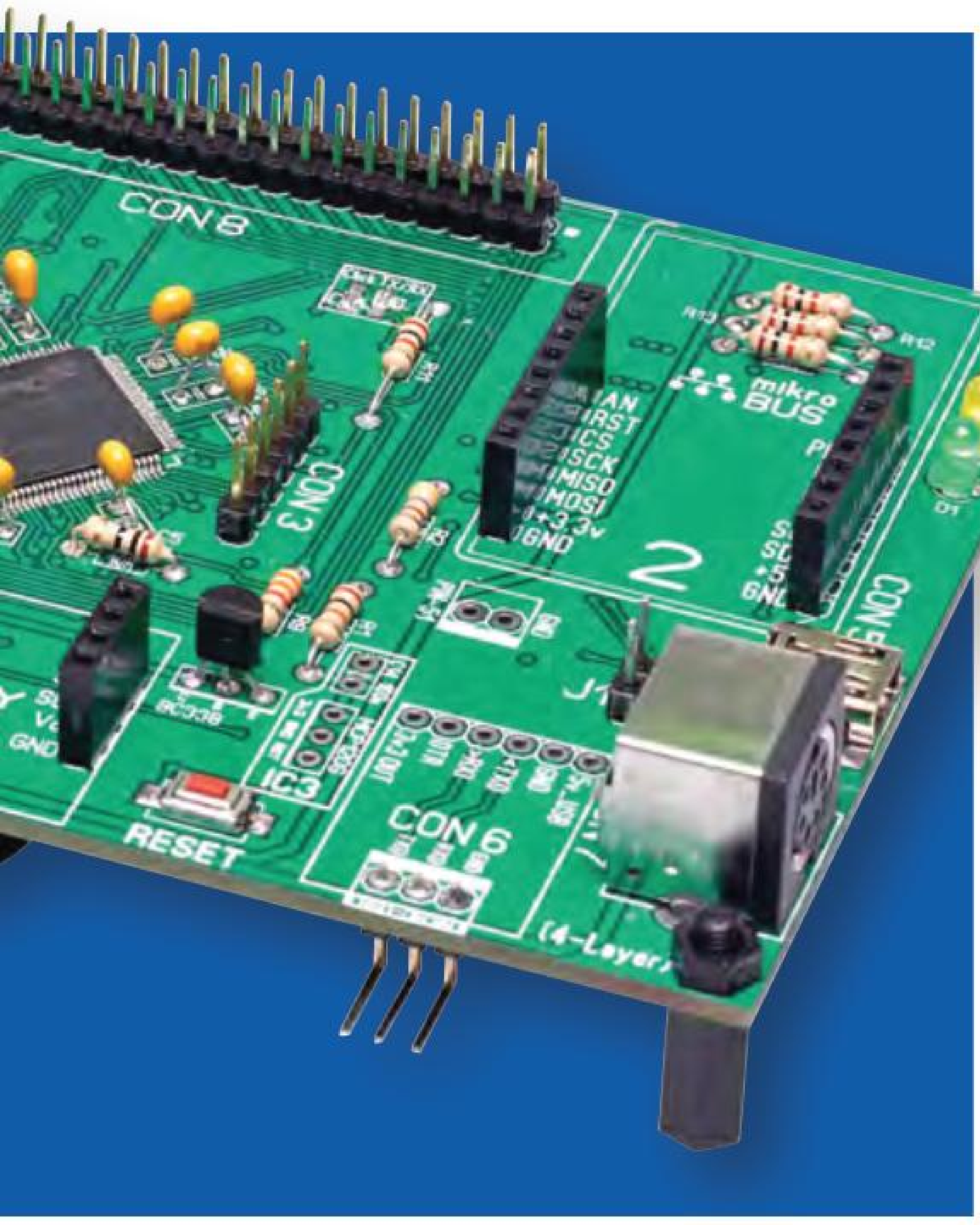
The files written are compatible with Windows, Mac and Linux systems, and to access the data it is as simple as popping the card out of its socket and into another computer. Or you can set up your program to read data off the card later and off-load it to a computer over a USB or serial interface.

The commands and functions related to the SD card are summarised in an accompanying panel. In addition, the *Micromite Plus User's Manual* has further details, so we will just go over the basics here.

Reading and writing to an SD card

To record data to the SD card, first open the file for writing, for example:

```
OPEN "file.txt" FOR OUTPUT AS #2
```



This instructs MMBasic to create the file ‘file.txt’ and prepare it for writing. If the file already exists, it will be overwritten (ie, erased) by this command. If you do not want to overwrite the file, open it **FOR APPEND**, which will leave the file as it is and ensure that any new data written will be added at the end. Note that file names must be in the 8.3 format – long file names are not currently supported.

The opened file is identified by a number (a file handle), in this case **#2**. You can use any number in the range #1 to #10, and this number is then used by all subsequent operations to identify the opened file.

To write text to the file, it’s just a matter of using the PRINT command. For example:

```
PRINT #2, “This line is saved in the file”
```

This is the same PRINT command that you use to display data on the console, the difference being that we have specified the file’s identifier as the first argument. As a result, MMBasic will direct the data to the file rather than to the console. The print command is very flexible and by using that one command, you can save any data, including numbers, strings or the contents of variables.

When you have finished with the file, you must tell MMBasic to close it. This will flush any buffered data and update the SD card’s file index. For example:

```
CLOSE #2
```

Reading from a file is similar to writing. First you must open it:

```
OPEN “file.txt” FOR INPUT AS #5
```

This instructs MMBasic to find the file ‘file.txt’ and prepare it for reading. There are a number of commands that you can use to read data but the easiest to understand is the **LINE INPUT** command, which will read a line (terminated with a carriage return character) from the file and save it in a variable. For example:

```
LINE INPUT #5, D$
```

The first line from the file will be copied into string variable D$. You can see what is stored in the variable by printing it to the console. For example:

```
PRINT D$
```

Subsequent reads will move through the file, returning one line each time. You can detect when you have reached the end of the file using the function **EOF(#ref)**, which will return true if the end has been reached. When you are finished with the file, you close it using the **CLOSE** command described above.

The previous examples were for sequential access, where you write new data to the end of the file and read through it sequentially from the start. However, the Micromite Plus also supports random access, which allows you to jump around in the file and change or read from any part of it. This is useful if you need to create a simple database or read a file out of sequence – see the **SEEK** and **LOC** functions listed in the accompanying panel.

Details on how to use these commands are in the *Micromite Plus Addendum* PDF.

Advanced graphics

The basic graphic commands and functions that are available on the standard 28 and 44-pin Micromites are also available on the Micromite Plus. In summary, these commands are:

CLS – Clear the screen.
PIXEL – Set the colour of an individual pixel.
LINE – Draw a line on the screen.
BOX – Draw a box on the screen. It can be optionally filled with another colour.
RBOX – Draw a box with rounded corners. This can also be filled with a colour.
CIRCLE – Draw a circle with a specified aspect ratio. As with boxes, this can be filled with a specified colour.
TEXT – Display text in a specific font with a specified colour.
GUI BITMAP – display a bitmap.

Using these commands, you can create reasonably advanced graphical displays, such as that shown in Fig.2, but it does take a lot of effort. However, the Micromite Plus offers an additional selection of commands that makes it much easier to create control/management displays. A good example is shown in Fig.1, which is a demonstration of a pump controller.

The on-screen graphic elements (eg, check boxes, switches) are created and managed by MMBasic, which makes writing this type of program much easier. These are known within MMBasic as GUI controls. A control is an on-screen graphical element that is created by the program, but is managed by MMBasic.

Spin box

An example of a typical control is the ‘spin box’, as shown in Fig.4. When the user touches the up or down icons, the number in the box will increment

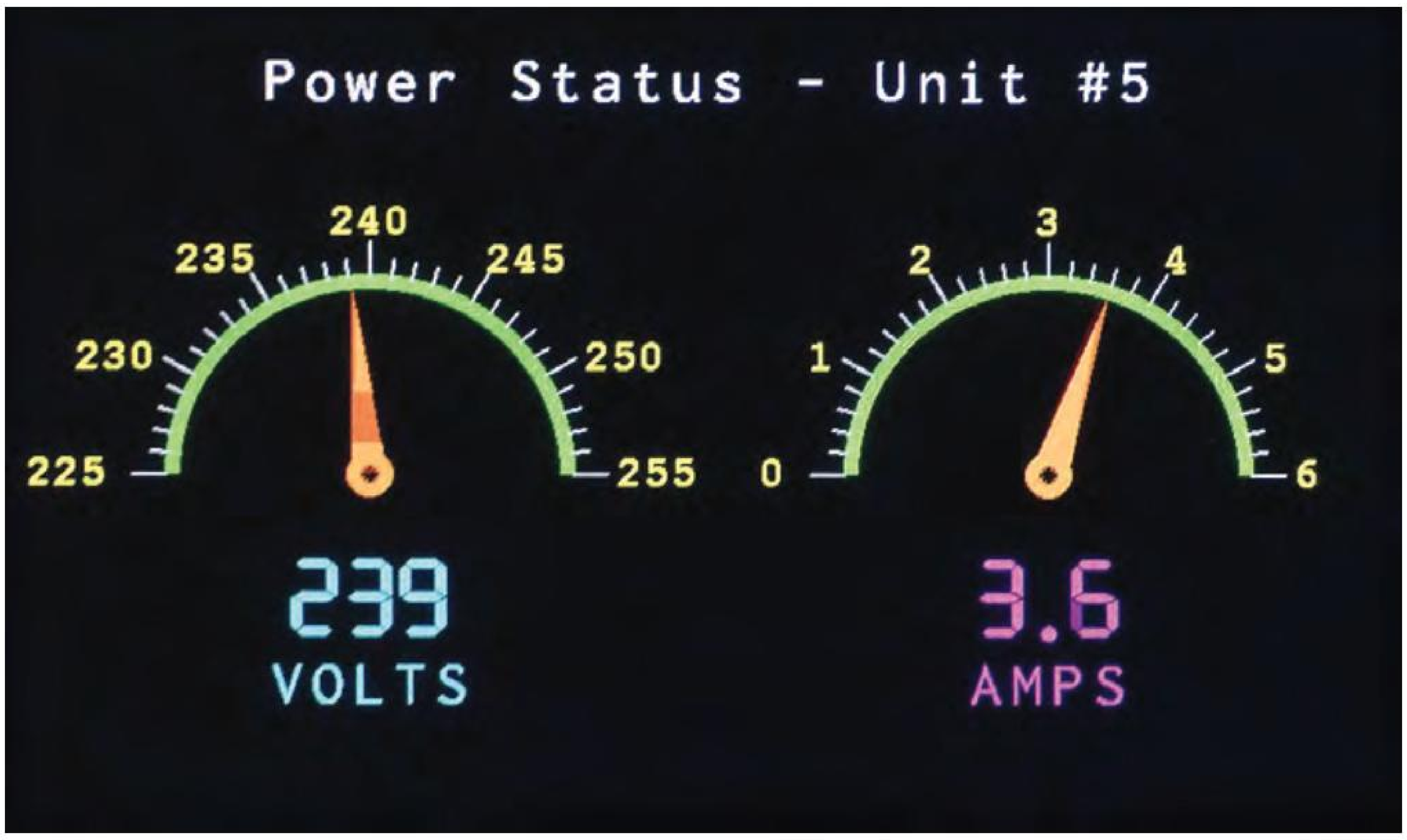


Fig.2: this is an example of a screen that was constructed using the standard graphics commands of the Micromite family (eg, LINE, CIRCLE). Images like this look very good because they are drawn at high resolution with a wide range of colours.

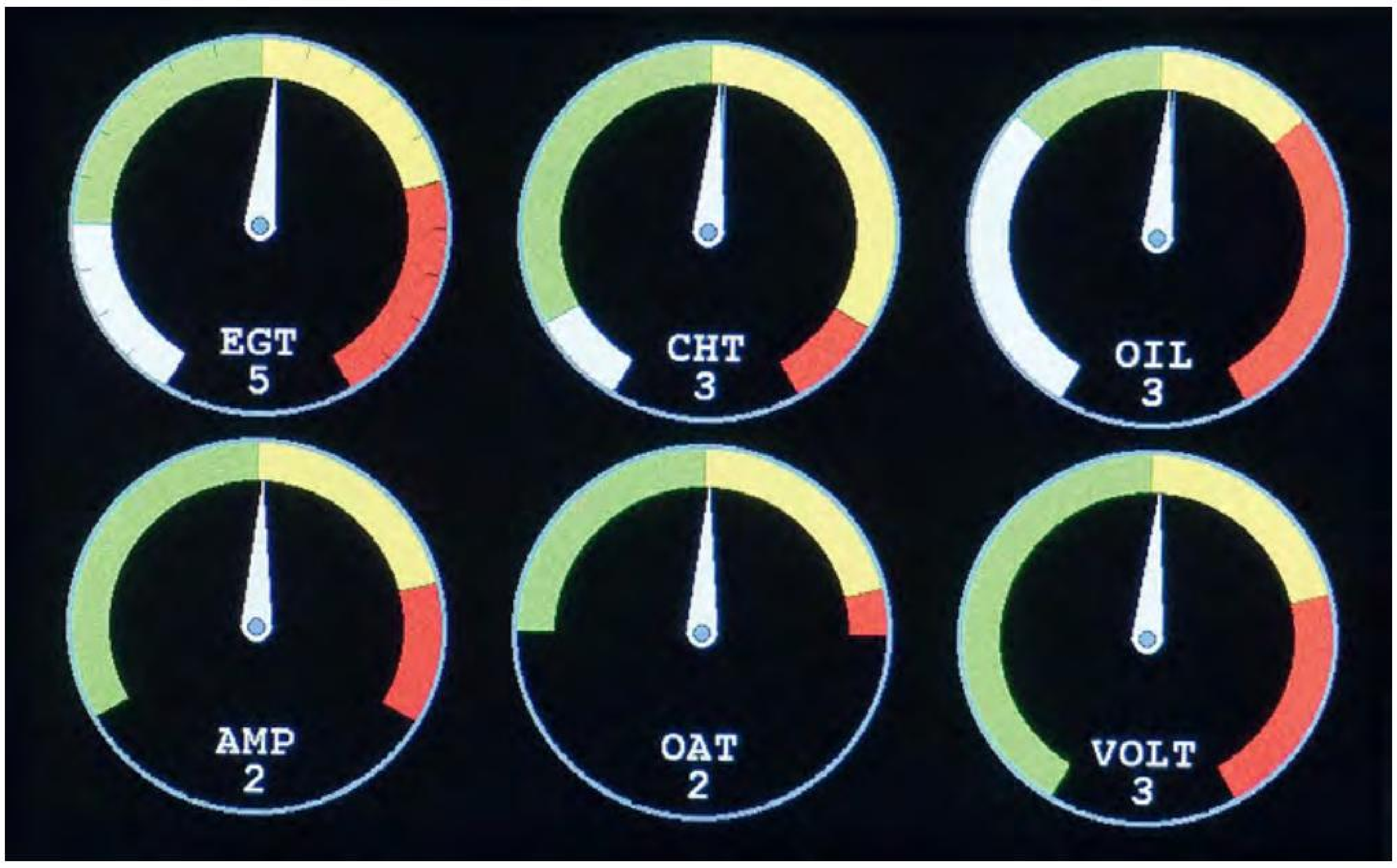


Fig.3: it's easy to show a lot of information on a single screen if using a large LCD panel. This is a simulation of an engine monitor, and although you cannot see it in the photograph, the meters update in real time with a smooth response.

or decrement. Holding down either will cause the action to continuously repeat. This control is handy for setting the level of something and is the digital equivalent of a potentiometer.

To create this control, the BASIC program uses the following command:

```
GUI SPINBOX #ref, StartX, StartY,
Width, Height, FColour, BColour,
Step, Minimum, Maximum
```

This takes a number of parameters:

(1) **#ref**: this is a unique reference number in the range 1-100 that identifies the control.

(2 and 3) **StartX and StartY**: these are the screen coordinates of the top left-hand corner of the control (including the up/down icons).

(4 and 5) **Width and Height**: the dimensions of the control (including the up/down icons).

(6 and 7) **FColour and BColour**: the colours used for the foreground and background when the control is drawn.

(8) **Step**: this is the amount by which the value in the spin box will change when the up and down icons are touched. It can be a fraction such as 0.1 or a whole number like 5.

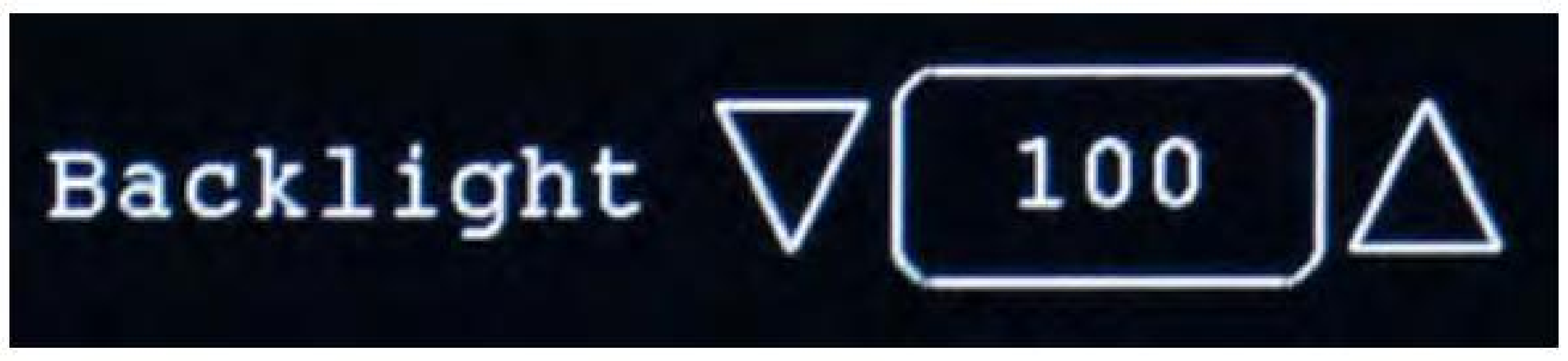


Fig.4: the SPINBOX control consists of a box displaying a number and up and down arrows at each end. It acts like a potentiometer; when either the up or down arrow is pressed, the number will increment or decrement by a set amount. If the touch is held down, the increment or decrement process will repeat at a fast rate.

(9 and 10) **Minimum and Maximum**: these are the limits for the value in the spin box. When they are reached, the up/down icons will not change the value beyond these limits. They are analogous to the end stops on a potentiometer.

When the **GUI SPINBOX** command is executed, MMBasic will draw the control on the LCD panel and the user can immediately start using it by touching the up/down icons. MMBasic will animate the control by illuminating the touched icons to provide visual feedback, updating the number displayed in the box and making a clicking sound (more on this later).

The animation is completely managed in the background by MMBasic. This allows the main BASIC program to be doing something completely different, eg, responding to changes in external sensor inputs.

Whenever the BASIC program needs to know the current value in the spin box, it can get this number using the **CTRLVAL(#ref)** function, where **#ref** is the reference number given to the control when it was created, for example:

```
PRINT CTRLVAL(#40)
```

will display the current value of control number #40 on the console.

Often, a program will also need to set the number in the spin box to some default value when the program is first run. This can be done with the following command, which can be executed at any time:

```
CTRLVAL(#ref) = number
```

This brief tutorial demonstrates all that is needed to create and use a GUI control within a BASIC program. MMBasic will do all the hard work while your program can be doing something more useful.

More controls

MMBasic has 11 different controls, including the spin box. The other controls are:

Check Box – this is a check box with a caption. When touched, an X will be drawn inside the box to indicate that this option has been selected and the control's value will be set to 1. When touched a second time, the check mark will be removed and the control's value will be zero.

Push Button – a momentary button which is a square switch with a caption on its face. When touched, the visual image of the button will appear to be pressed (on) and the control's value will be 1. When the touch is removed, the image will return to the off state and the value will revert to zero.

Switch – the switch control will draw a latching switch with a caption on its face. When touched, the visual image of the button will appear to be pressed and the control's value will be 1. When touched a second time, the switch will be released and the value will revert to zero.

Radio Button – this will draw a radio button with a caption beside it. When touched, the centre of the button will be illuminated to indicate that this option has been selected and the control's value will be 1.

Radio buttons are grouped together when surrounded by a frame (see below) and when one button in the group is selected, all the others in the group will be deselected. If a frame is not used, all buttons on the screen will be grouped together.

Frame – a frame is a box with round corners and a caption. It does not respond to touch but is useful when a group of controls need to be brought together. It can also used to surround a group of radio buttons and MMBasic will arrange for the radio buttons surrounded by the frame to be exclusive, as described above.

LED – this is an indicator light (it looks like a panel-mounted LED) with a caption. When its value is set to non-zero it will be illuminated and when it is set to zero, it will be off (a dull version of its colour). If needed, the colour of the LED can be changed on the fly. The LED graphic does not respond to touch.

Display box – a box with rounded corners containing some text. Any text can be displayed in the box by using the **CTRLVAL(#ref) =** command. It does not respond to touch and is useful for

SD card functions

MMBasic on the Micromite Plus supports the standard BASIC commands for working with storage systems. This is a brief summary; the *Micromite Plus Addendum* PDF goes into more detail:

- OPEN fname$ FOR mode AS #fnbr – open a file for reading or writing.
- PRINT #fnbr, expression [[,;]expression] . . . etc – output text to the file opened as #fnbr.
- INPUT #fnbr, list of variables – read a list of comma-separated data into the variables specified from the file previously opened as #fnbr.
- LINE INPUT #fnbr, variable$ – read a complete line into the string variable specified from the file previously opened as #fnbr.
- CLOSE #fnbr [,#fnbr] . . . – close the file(s) previously opened with the file number '#fnbr'.

Programs and images can be loaded from the SD card while programs can also be saved:

- LOAD fname$ [, R] – load a BASIC program from the SD Card. ',R' will cause the program to also be run.
- SAVE fname$ – save the current program to the SD card.
- LOAD IMAGE filename$ [, StartX, StartY] – loads a BMP image from the SD card and displays it on the attached LCD display.

Basic file and directory manipulation can be done from within a BASIC program:

- FILES [wildcard] – search the current directory and list the files/directories found.
- KILL fname$ – delete a file in the current directory.
- MKDIR dname$ – make a sub-directory in the current directory.
- CHDIR dname$ – change to the directory dname$.
- RMDIR dir$ – remove or delete the directory 'dir$' on the SD card.
- SEEK #fnbr, pos – will position the read/write pointer in a file that has been opened for RANDOM access.

There are also a number of functions that support the above commands:

- INPUT$(nbr, #fnbr) – will return a string composed of 'nbr' characters read from a file previously opened for INPUT.
- DIR$(fspec, type) – will search an SD card for files and return the names of entries found.
- EOF(#fnbr) – will return true if the file with the file number #fnbr is positioned at the end of the file.
- LOC(#fnbr) – for a file opened as RANDOM, this will return the current position of the read/write pointer in the file.
- LOF(#fnbr) – will return the current length of the file in bytes.

displaying text, numbers and messages.

Caption – this will draw a text string on the screen. It is similar to the basic drawing command **TEXT**, the difference being that MMBasic will automatically manage this control by dimming or hiding it when needed.

Text Box – an advanced control that allows the user to enter text via an on-screen QWERTY keyboard. Normally, this control is just a rounded box containing some text, but when touched, a full QWERTY keyboard will appear and all other controls will be dimmed and disabled – see Fig.5. Using this virtual keyboard, any text can be entered into the box, including upper/lower case letters, numbers and any other characters in the ASCII character set.

Number Box – a number box is similar to the text box described above except that when touched, it will display a numeric keypad on the screen. Using this virtual keypad, any number can be entered into the box, including a floating point number in exponential format. The new number will replace the number previously in the box.

Click sound

When a control is touched, it is animated by MMBasic to provide visual feedback to the person touching it. To add to the impression that this is a physical object, MMBasic can also generate a click sound at the same time.

This is done by adding a standard piezo buzzer to an I/O pin and telling the Micromite Plus the pin number in the **OPTION TOUCH** command. Then, whenever a touch-sensitive control is touched, MMBasic will generate a short pulse on that pin to produce a simulated click sound.

Transistor driver

The I/O pins on the Micromite Plus do not have sufficient drive capability for most piezo buzzers, so you should use a transistor as the driver. The Explore 100 does this and it provides a good example of how to implement this feature.

Reference numbers

All controls are identified with a reference number when first created. This number is then used whenever you want to do something associated with the control. The number must be in the range of 1-100, which caters for up to 100 simultaneously active controls in a program.

For example, you might create a switch with a reference number of 41 and then later hide it:

```
GUI SWITCH 41, c$, x, y, etc
GUI HIDE 41
```

In a program with a lot of controls, using simple numbers can be confusing. For example, what do controls that have been designated 87 and 41 do?

For this reason, it is good practice to define the control reference numbers as a constant with a meaningful name. You can then use the name throughout your program and it will be obvious to the casual reader what the control does. For example:

```
CONST PwrSwitch = 41
GUI SWITCH PwrSwitch, c$, x, y, etc
GUI HIDE PwrSwitch
```

Interacting with controls

Most controls have a value which can be read and set. For example, you can read the value of a check box with the **CTRLVAL(#ref)** function. You can also set the value by assigning a value to the function (ie, using it as a command), for example:

```
CTRLVAL(#ref) = 1
```

will set the value of the check box to true **and** cause the visual image of the check box to be checked – just as if the user had touched the on-screen

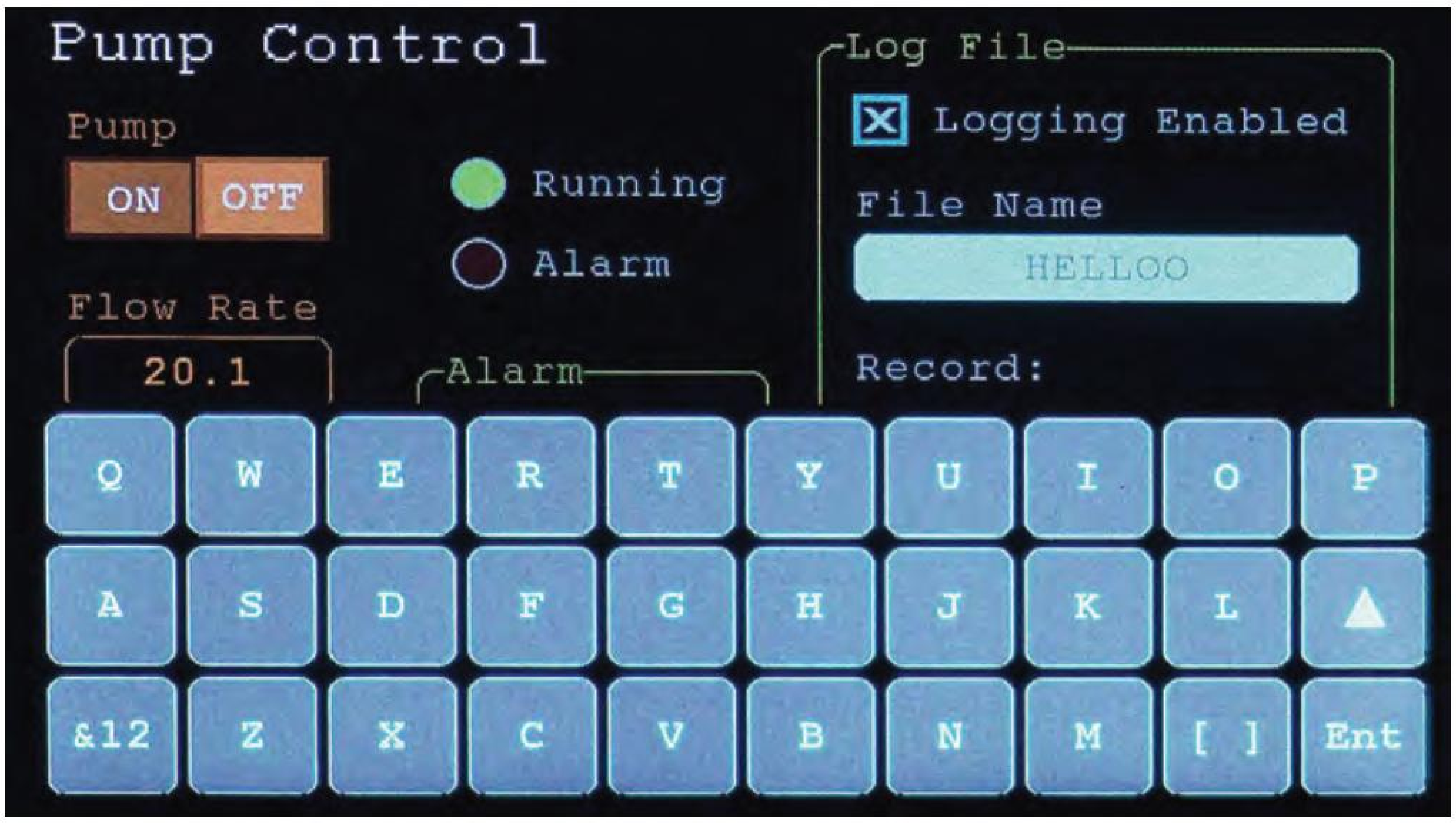


Fig.5: the Text Box control displays a full on-screen QWERTY keyboard when touched. This allows the user to enter any text using the full ASCII character set, including numbers and punctuation. The up arrow will shift lower/upper case and the '&12' key will change the keyboard to a number and punctuation layout. Note that the other objects on the screen are automatically dimmed to indicate that they cannot be used while the keyboard is on the screen.

check box. This is useful when setting defaults and interacting with other controls.

The value returned by this function depends on the control; for some it is a number and for others it is a string. MMBasic will automatically return the correct type of data and will also expect the correct type of data when you are setting a value. For example, setting the value of a frame will change the caption of the frame (which is a string) and therefore you must supply a string.

Modifying a control

There are a range of commands and functions that you can use to modify a control after it has been created. They include:

GUI FCOLOUR – changes the foreground colour of the control. This is especially useful for the LED control.

GUI BCOLOUR – changes the background colour of a control.

GUI DISABLE – disables one or more control(s). Disabled controls do not respond to touch and will be dimmed on the screen.

GUI ENABLE – undoes the effects of GUI DISABLE and restores the control(s) to normal operation.

GUI HIDE – hides one or more control(s). Hidden controls will not respond to touch and will be replaced on the screen with the current background colour (ie, they are erased).

GUI SHOW – undoes the effects of **GUI HIDE** and restores the controls to full visibility and normal operation.

GUI DELETE – deletes one or more controls. This includes removing the image of the control from the screen and freeing the memory used by the control.

Next month

That's it for now. Next month, we'll get into more advanced topics such as touch interrupts, screen pages and message boxes.

YouTube video

The author has produced a video which describes and demonstrates the capabilities of the Micromite Plus. You'll find it at:

https://youtu.be/j12LidkzG2A

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WIN A
Micromite+
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This month, *EPE* and **MicroMite.org** are giving you the chance to win a MicroMite+ so that you may practice some of the Advanced Micromite Programming techniques as described on pages 28 to 32.

The prize is a fully assembled MicroMite+ LCD BackPack Module, complete with 2.8" Touch Screen. Think of this as a super-charged BackPack featuring an Explore64 Module (with uSD socket), complete with the electronics to drive a Touch TFT, all on a single compact board.

To enter simply send an email to **epe@micromite.org** describing what solution you would build when applying some of the Advanced Micromite Programming techniques.

Make the email subject: **BP64**, and ensure it reaches us before the closing date: **30th November**

The name of the lucky winner will be published in a future edition of *EPE*.

Look out for future competitions to win other fantastic Micromite products

(**PLEASE NOTE:** No SD card is included; however the 2.8" Touch TFT is!)

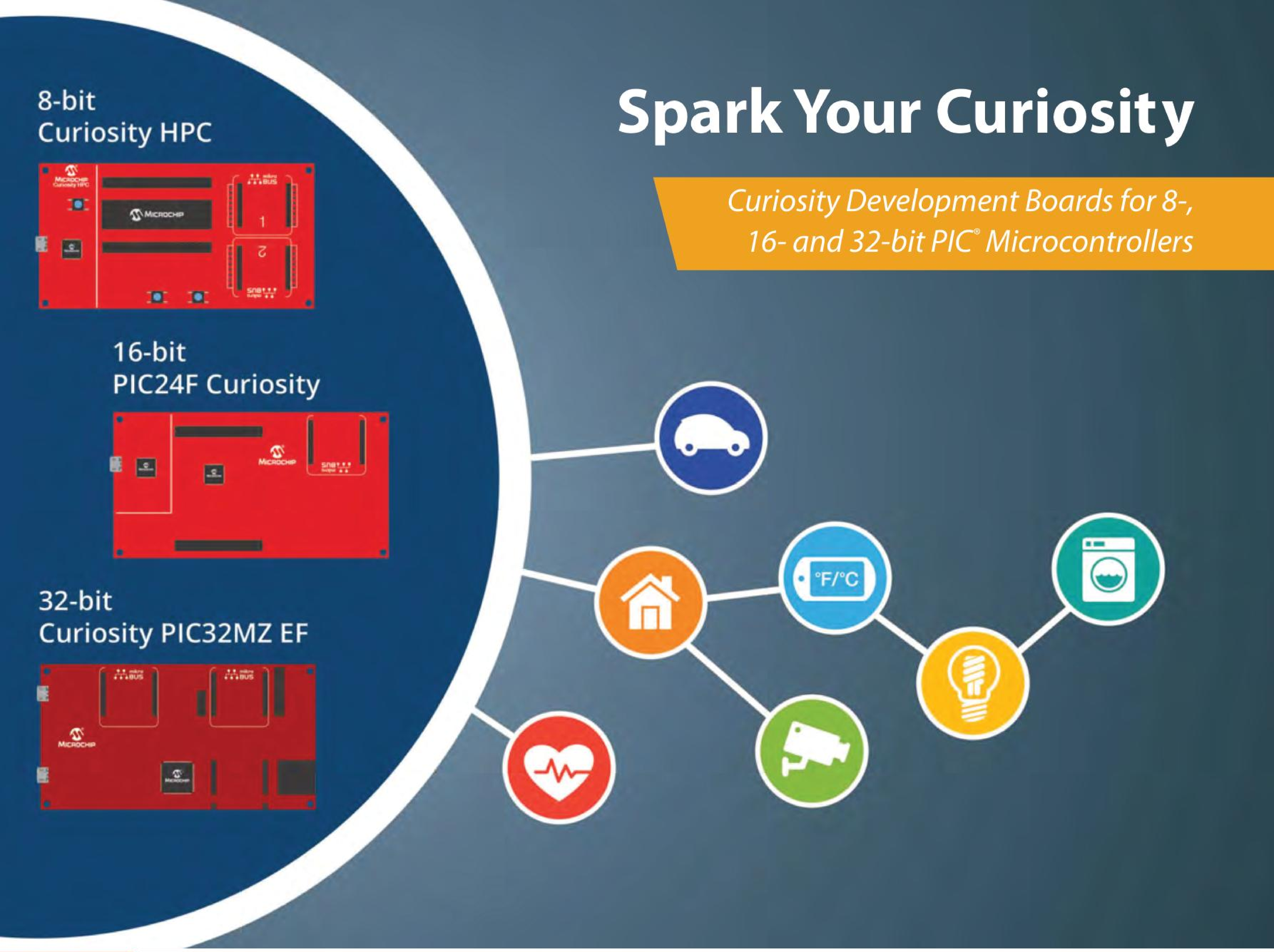
Good Luck!

We are pleased to announce the winner from the September 2017 issue of *EPE*:

Aaron Herkanaidu (from St Albans) wins a Fully Assembled Explore100 Module with his 'RaspberryPi HAT adaptor module'

Well done Aaron!

T&Cs
1. You may enter as many times as you wish
2. All entries must be received by the closing date
3. Winners will be notified by email within one week after the closing date
4. Winners will need to confirm a valid address for their prize to be shipped
5. UK winners will have their prize sent via Royal Mail's Special Delivery service
6. Overseas winners will have their prize sent by Royal Mail's International Tracked & Signed service



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Teach-In 2018

Get testing! – electronic test equipment and measurement techniques

Part 2: Oscilloscopes

by Mike Tooley

Welcome to *Teach-In 2018: Get testing! – electronic test equipment and measurement techniques*. This *Teach-In* series will provide you with a broad-based introduction to choosing and using a wide range of test gear, how to get the best out of each item and the pitfalls to avoid. We'll provide hints and tips on using, and – just as importantly – interpreting the results that you get. We will be dealing with familiar test gear as well as equipment designed for more specialised applications.

Our previous *Teach-In* series have dealt with specific aspects of electronics, such as PICs (*Teach-In 5*), Analogue Circuit Design (*Teach-In 6*) or popular low-cost microcontrollers (*Teach-In 7* and *8*). The current series is rather different because it has been designed to have the broadest possible appeal and is applicable to all branches of electronics. It crosses the boundaries of analogue and digital electronics with applications that span the full range of electronics – from a single-stage transistor amplifier to the most sophisticated microcontroller system. There really is something for everyone in this series!

Each part includes a simple but useful practical *Test gear project* that will build into a handy gadget that will either extend the features, ranges and usability of an existing item of test equipment or that will serve as a stand-alone instrument. We've kept the cost of these projects as low as possible and most of them can be built for less than £10 (including components, enclosure and circuit board).

This month

In Part 2 this month, *In theory* will introduce the oscilloscope ('scope' for short), an invaluable tool that will allow you to 'see' inside an electronic circuit. *Gearing up* describes different types of scope, ranging from older CRT-based instruments to external USB modules that can be used with a tablet, laptop or desktop computer. *Get it right!* helps you avoid some pitfalls and provides important tips on how to get the best out of your scope. Finally, our second *Test Gear Project* is a handy scope calibrator that will allow you to check your scope's performance. It also provides you with a useful signal source that will prove invaluable later in this *Teach-In 2018* series.

In theory: the oscilloscope

Testing to specification

If you are enthusiastic about electronics above a superficial level, then sooner or later you will need a means of displaying time-related waveforms of the signals and voltages in your circuits. To do this, you will need some form of oscilloscope. Depending on the depth of your pockets, you can purchase such an instrument for as little as £50 or over £5000 – and at first glance the choice of instrument can be somewhat bewildering due to the huge variation in features, displays, controls and specifications offered.

An oscilloscope can provide a great deal of information about what is going on in a circuit. In effect, it allows you to 'see' into the circuit, displaying waveforms that correspond to the signals and voltages that are present. For convenience, we have divided oscilloscopes into four main categories:

- Analogue CRT-based scopes
- Self-contained digital storage scopes (DSO)
- External USB scopes based on fast analogue-to-digital converters (ADC)
- Sound card scopes using a PC or laptop with no external hardware.

Within each of these main categories there are a host of sub-categories. For example, scopes with multi-channel capability, high-resolution scopes or scopes with built-in signal/waveform generators. We will start by looking at the traditional CRT-based analogue scope.

CRT-based scopes

Despite the advent of modern digital storage scopes (DSO) using fast analogue-to-digital converters (ADC), CRT-based instruments can still be found in many workshops and laboratories. Frequently available at budget prices, such instruments can deliver excellent performance at low cost.

The simplified block schematic of a generic CRT-based analogue scope is shown in Fig.2.2. The cathode-ray tube (CRT) requires a high-voltage supply (usually several kV). Within the CRT a beam of electrons is focussed on the phosphor coating at the rear of the display screen. The beam is deflected in the horizontal (*x*-axis) and vertical (*y*-axis) by means of two sets of internal plates (the X- and Y-plates respectively). In normal operation (ie, to display a time-related voltage waveform) the amplified

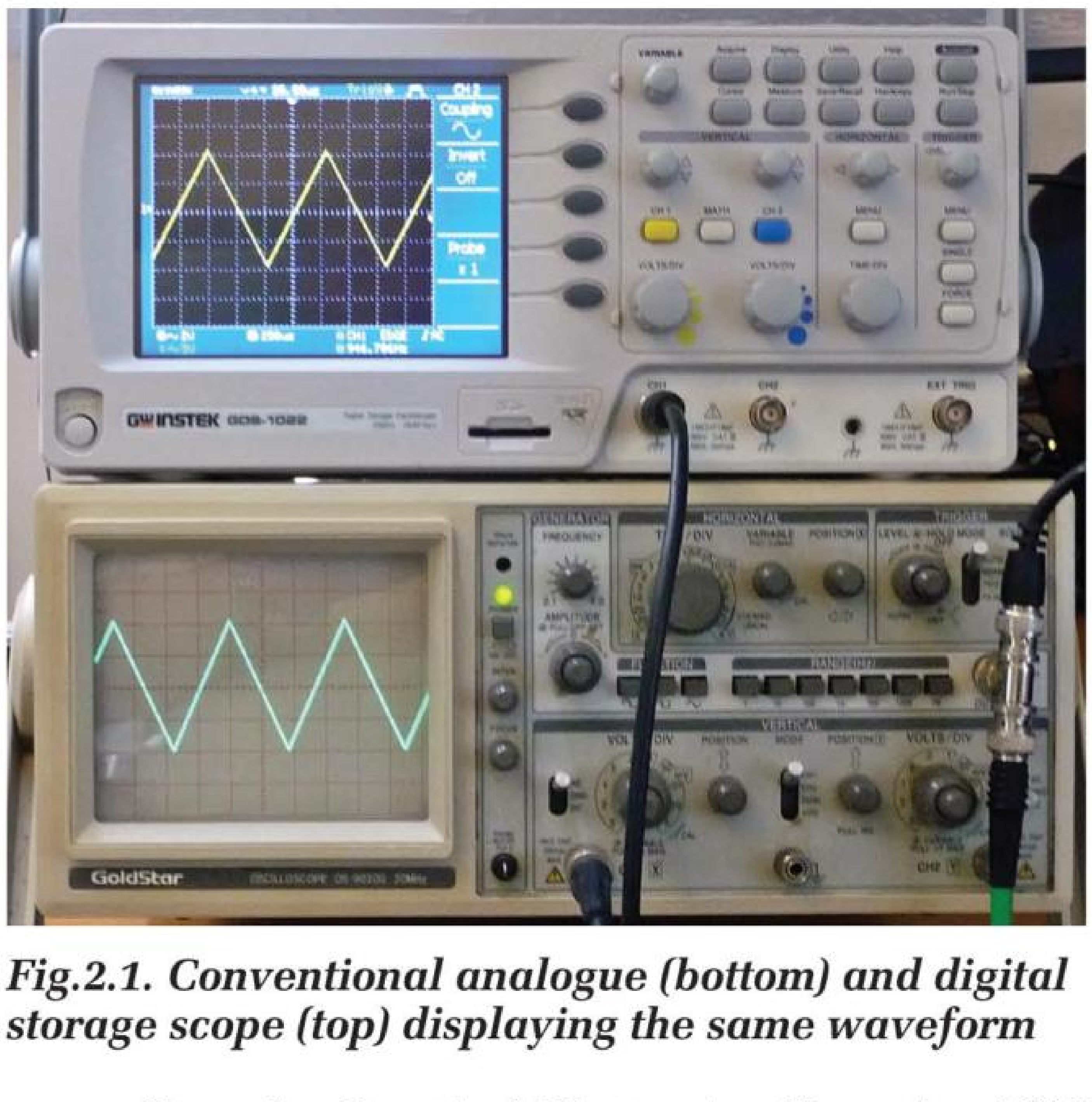


Fig.2.1. Conventional analogue (bottom) and digital storage scope (top) displaying the same waveform

signal voltage is applied to the Y-plates and a linear ramp waveform is applied to the X-plates (often referred to as the timebase waveform).

The time taken for the ramp sets the speed at which the beam moves across the screen along the time (*x*) axis. For example, if the timebase is set to 1ms/cm the beam would move through 1cm each millisecond. If the waveform under investigation had a frequency of 1kHz, one complete cycle would be displayed for every cm on the screen. If the screen had a width of 10cm then ten complete cycles of the waveform would appear on it.

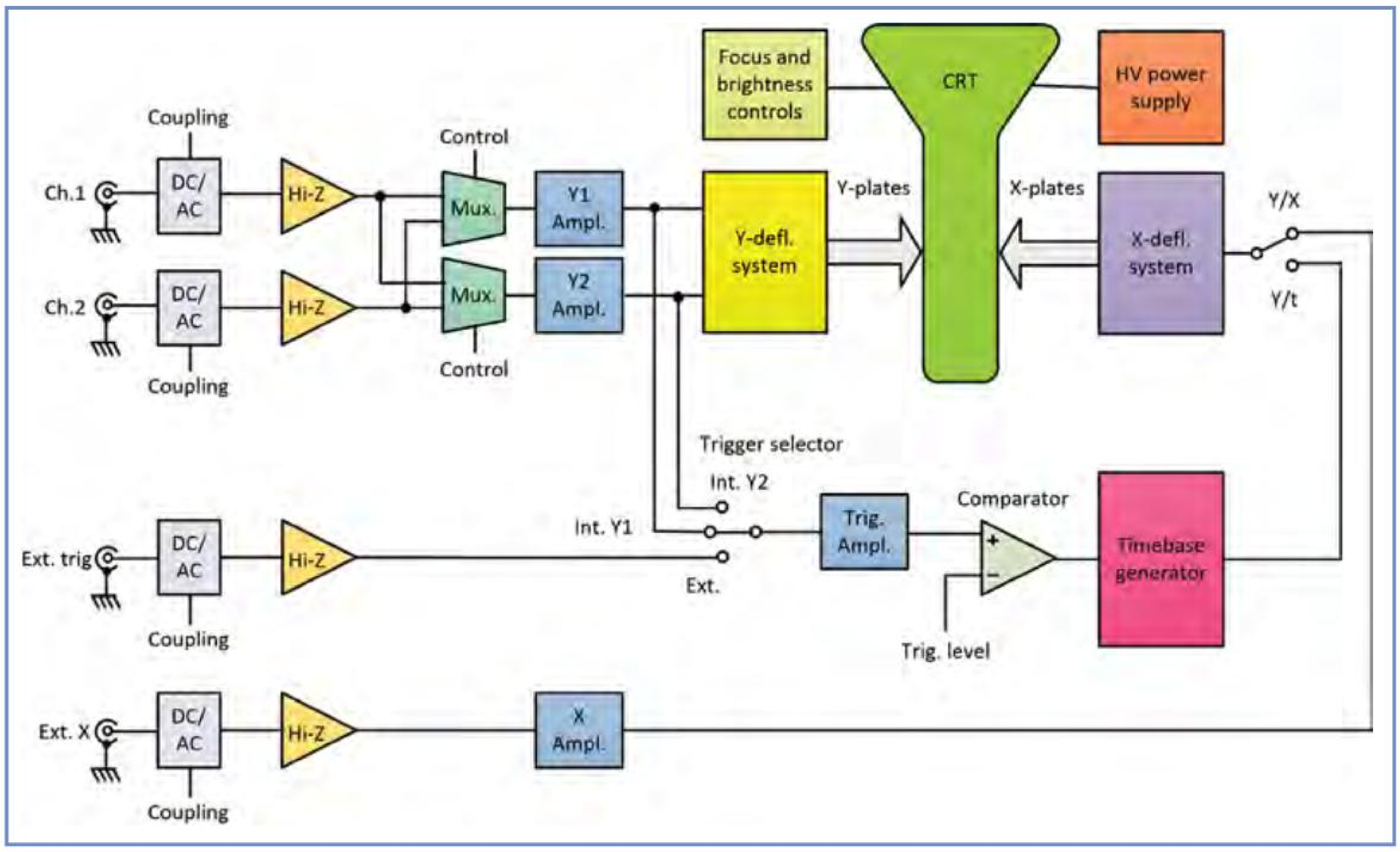


Fig.2.2. Simplified block schematic of an analogue CRT-based oscilloscope

The CRT is fitted with a graticule that may either be integral with the tube face or is a separate translucent sheet. The graticule is usually ruled with a 1cm grid to which further bold lines may be added to mark the major axes on the central viewing area. Accurate voltage and time measurements may be made with reference to the graticule, applying a scale factor derived from the appropriate range switch. A word of caution is appropriate at this stage, however. Before taking meaningful measurements from the CRT screen it is essential to ensure that the variable controls are set in the calibrate (CAL) position. Results will almost certainly be inaccurate if this is not the case!

Using a CRT-based scope

If you've not used a CRT-based scope before, the controls and adjustments can be baffling. In Fig.2.4 we've summarised the controls and adjustments found on most typical mid-range CRT-based instruments. You might find that it takes some time to get familiar with a scope of this type, but the investment in time and effort can be very rewarding as it will allow you to get the very best out of the instrument. The procedure and adjustments differ according to the type of waveform being investigated and whether the instrument is being used to display a single waveform (single-channel operation) or whether it is being used to display two waveforms simultaneously (dual-channel operation).

Input stage coupling

Normally, an oscilloscope employs DC coupling throughout the vertical deflection system and a shift along the vertical axis will occur whenever a direct voltage is present at the input. When investigating waveforms in a circuit you will often encounter a signal (AC) superimposed on a DC level, which may be removed by inserting a capacitor in series with the signal. With AC coupling selected (see Fig. 2.2) a capacitor is inserted in the input signal path. When DC coupling is selected the capacitor is shorted and any DC level at the input is passed directly into the vertical deflection system.

On most scopes an additional 'Ground' position (not shown in Fig. 2.2) is made available. When this is selected, the vertical input is taken to directly to ground/common (0V) and the oscilloscope input is left floating. This facility is useful in allowing the accurate positioning of the vertical position control along the 0V axis. If the control is then set to DC, the magnitude of any DC level present at the input may be easily measured by examining the shift along the vertical axis. The input coupling stage is followed by a wideband DC-coupled amplifier with high-input impedance. This ensures that signals are faithfully displayed without added distortion due to reduced high-frequency response. The high input impedance helps to avoid loading effects on the circuit under investigation. We will return to this important point when we discuss scope probes later.

Multiplexing

Dual-channel scopes are able to display either of the two channels selected independently or both channels at the same time. This feature will allow you to compare two signals against a common time scale. An example of when this is might be useful is when investigating the input and output waveforms of an amplifier (where you would expect the output waveform to be a faithful copy of the input waveform). In addition to displaying the two channels separately you might sometimes find it useful to display the sum or difference of the two waveforms. This is accomplished using the two multiplexers shown in Fig. 2.2.

Triggering

To provide a stable display, it is necessary to synchronise the timebase waveform with the signal under investigation. This is achieved by means of a trigger circuit comprising an amplifier and comparator. The trigger input can be taken from either of the input channels or from an external signal source. The comparator sets the signal voltage level

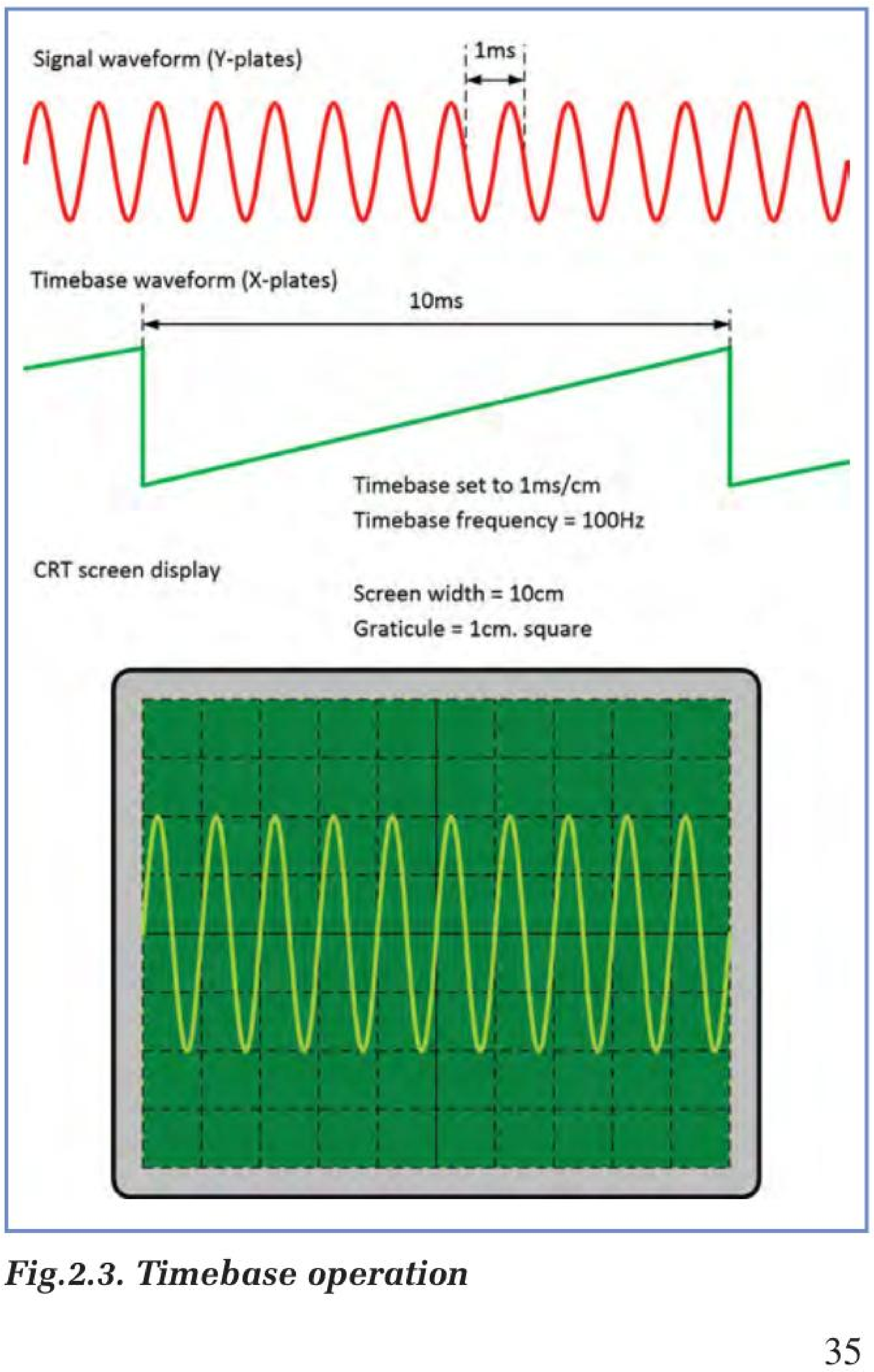


Fig.2.3. Timebase operation

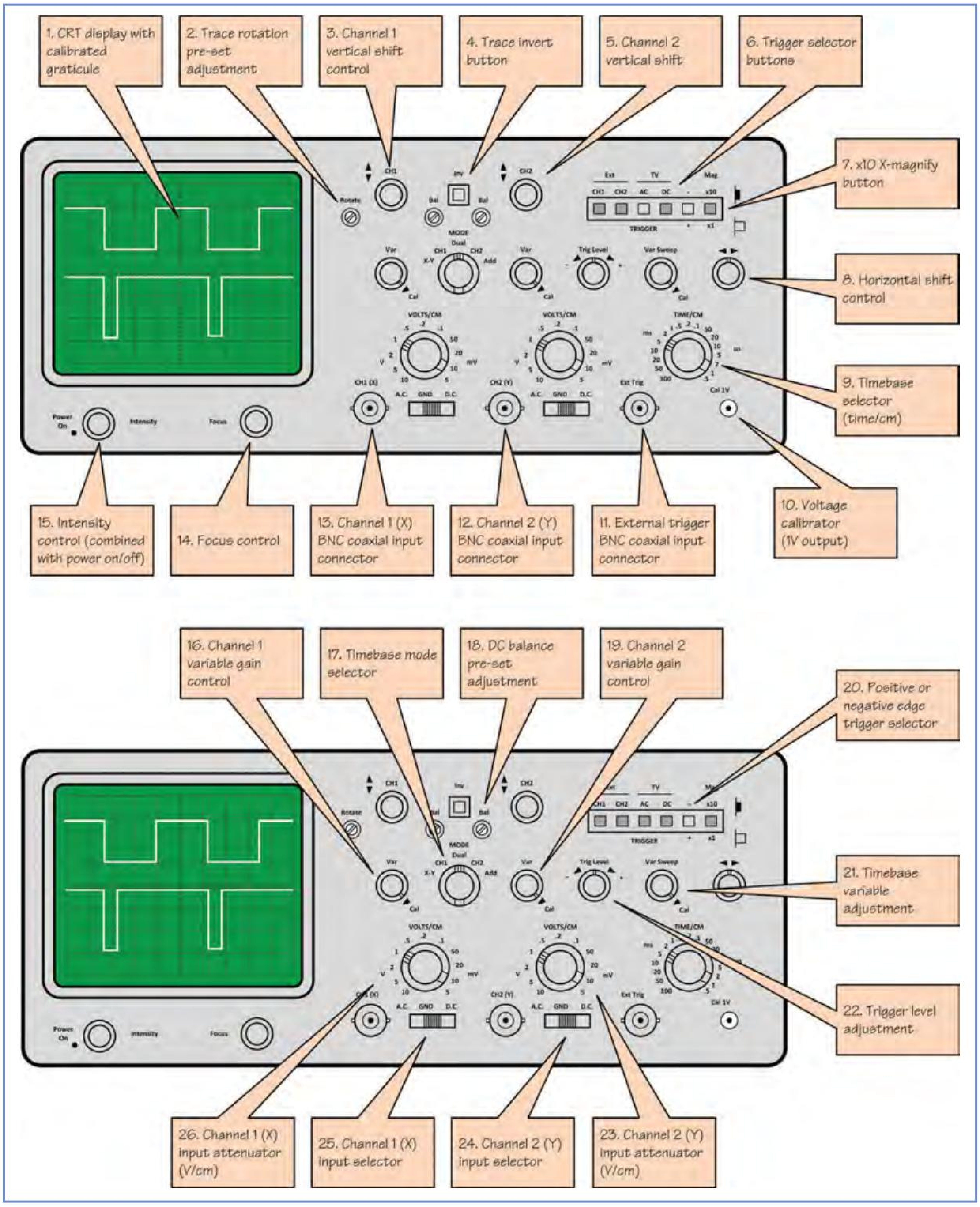

1. CRT display with calibrated graticule
2. Trace rotation pre-set adjustment
3. Channel 1 vertical shift control
4. Trace invert button
5. Channel 2 vertical shift
6. Trigger selector buttons
7. x10 X-magnify button
8. Horizontal shift control
9. Timebase selector (time/cm)
10. Voltage calibrator (1V output)
11. External trigger BNC coaxial input connector
12. Channel 2 (Y) BNC coaxial input connector
13. Channel 1 (X) BNC coaxial input connector
14. Focus control
15. Intensity control (combined with power on/off)
16. Channel 1 variable gain control
17. Timebase mode selector
18. DC balance pre-set adjustment
19. Channel 2 variable gain control
20. Positive or negative edge trigger selector
21. Timebase variable adjustment
22. Trigger level adjustment
23. Channel 2 (Y) input attenuator (V/cm)
24. Channel 2 (Y) input selector
25. Channel 1 (X) input selector
26. Channel 1 (X) input attenuator (V/cm)

Fig.2.4. Controls and adjustments available on a typical dual-channel analogue oscilloscope

at which the timebase waveform is triggered, and it allows you to select a specific point on the input waveform at which the trace starts. Most scopes will allow you to select positive or negative edge triggering, as well as triggering at a specific signal voltage level.

Power supply

One significant disadvantage of a CRT-based oscilloscope is the need for a high-voltage power supply (typically 1.2kV, or more). The final anode connection (and internal phosphor coating) is maintained at a high potential while the heated cathode connection is maintained at a relatively low potential. Internal grids provide a means of focussing and brightness control.

Beam splitting

The chopped-alternate control (not shown in Fig. 2.2) available in dual-beam oscilloscopes allows you to select the mode used for splitting the vertical beam deflection between the two input channels (Y1 and Y2). In the chopped position, the trace displays a small portion of one vertical channel waveform followed by an equally small portion of the other. The traces are, in effect, sampled at a relatively fast rate, the result being two apparently continuous displays. In the alternate position, a complete horizontal sweep is devoted to each channel alternately.

Basic waveform measurements

The most common use for a scope is investigating waveforms present in a circuit. To reduce the likelihood of picking up hum and noise, the scope should be connected to the circuit under investigation using a matched scope probe (see page 40). This comprises a screened lead fitted with an insulated probe, contact tip and crocodile clip ground connection. The outer screen is connected to the common 0V rail, while the probe is simply moved around the circuit from point to point. Note that, because of the scope's ground connection, it is not usually possible to display a waveform that appears 'across' a component (eg, between the base and emitter of a transistor). For this reason, waveforms are nearly always displayed relative to ground (or common).

By investigating waveforms, it is usually possible to determine whether distortion is present. Different forms of distortion have a different effect on a waveform and thus it is possible to determine which type of distortion is present. A 'pure' sinewave is used as an input signal and the output is then displayed on the oscilloscope. We will be returning to this important topic in Part 5 of *Teach-In 2018*, where we will be looking at techniques used for performing a wide range of audio frequency measurements.

Fig.2.5(a) shows a sinewave which comprises consecutive positive and negative half-cycles. The periodic time (T) is the time measured for one complete cycle of the waveform. The period can be measured at consecutive positive-going zero-axis crossing points, as shown in Fig.2.5(a), but it is often more convenient to measure between consecutive positive (or negative) peaks.

The frequency of a waveform is simply the number of complete cycles of the wave that occur in a time interval of 1s. Frequency is expressed in hertz (Hz). Hence, a wave that has a period of 1s will have a frequency of 1Hz. Similarly, a wave that has a period of 1ms will have a frequency of 1kHz. The relationship between frequency (f) and periodic time is simply given by:

$$f = 1/T$$

where f is the frequency in hertz and T is the periodic time in s.

In the case of a symmetrical bipolar waveform like that shown in Fig.2.5(a),

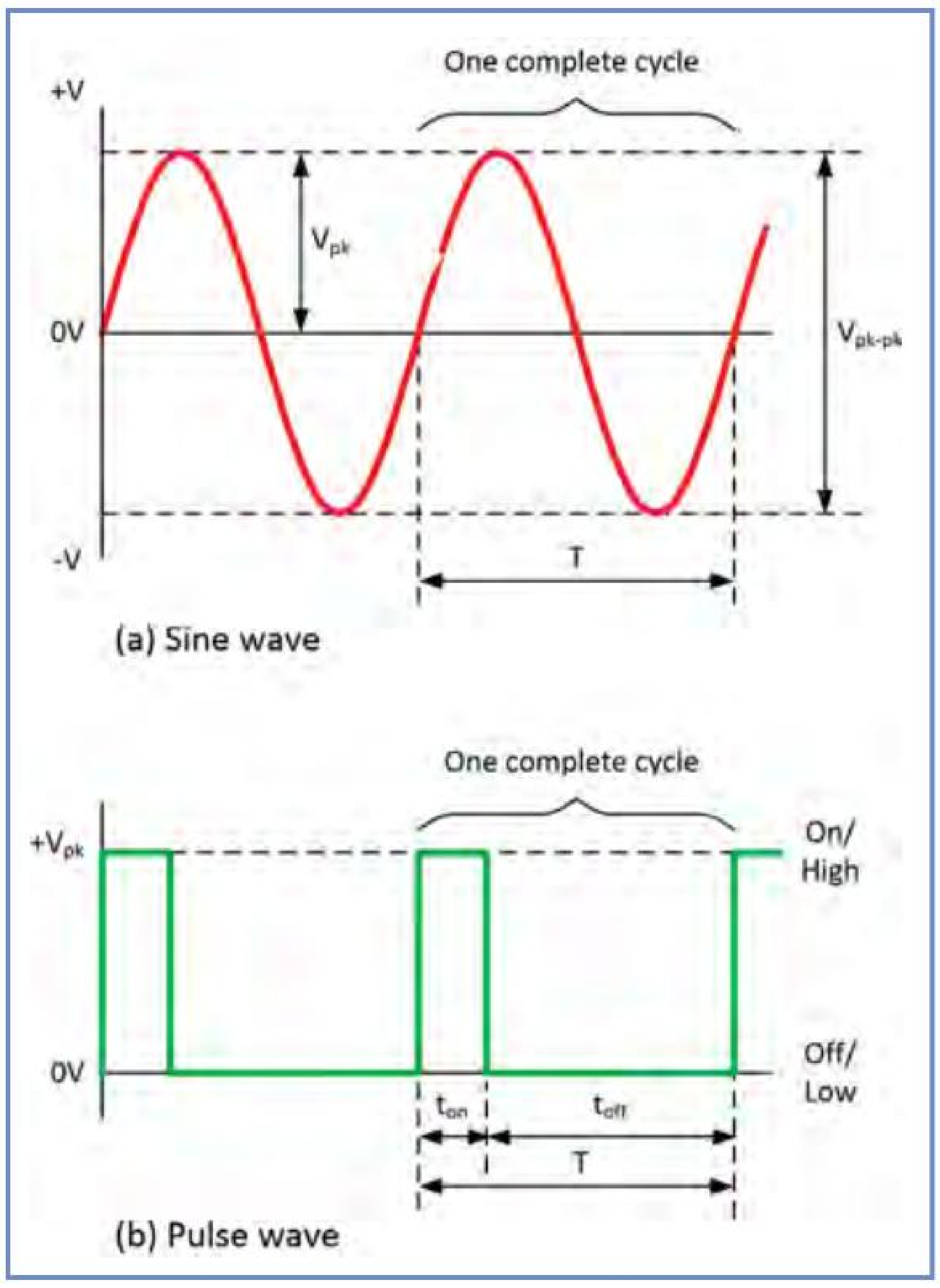


Fig.2.5. Basic parameters of sine and rectangular waves

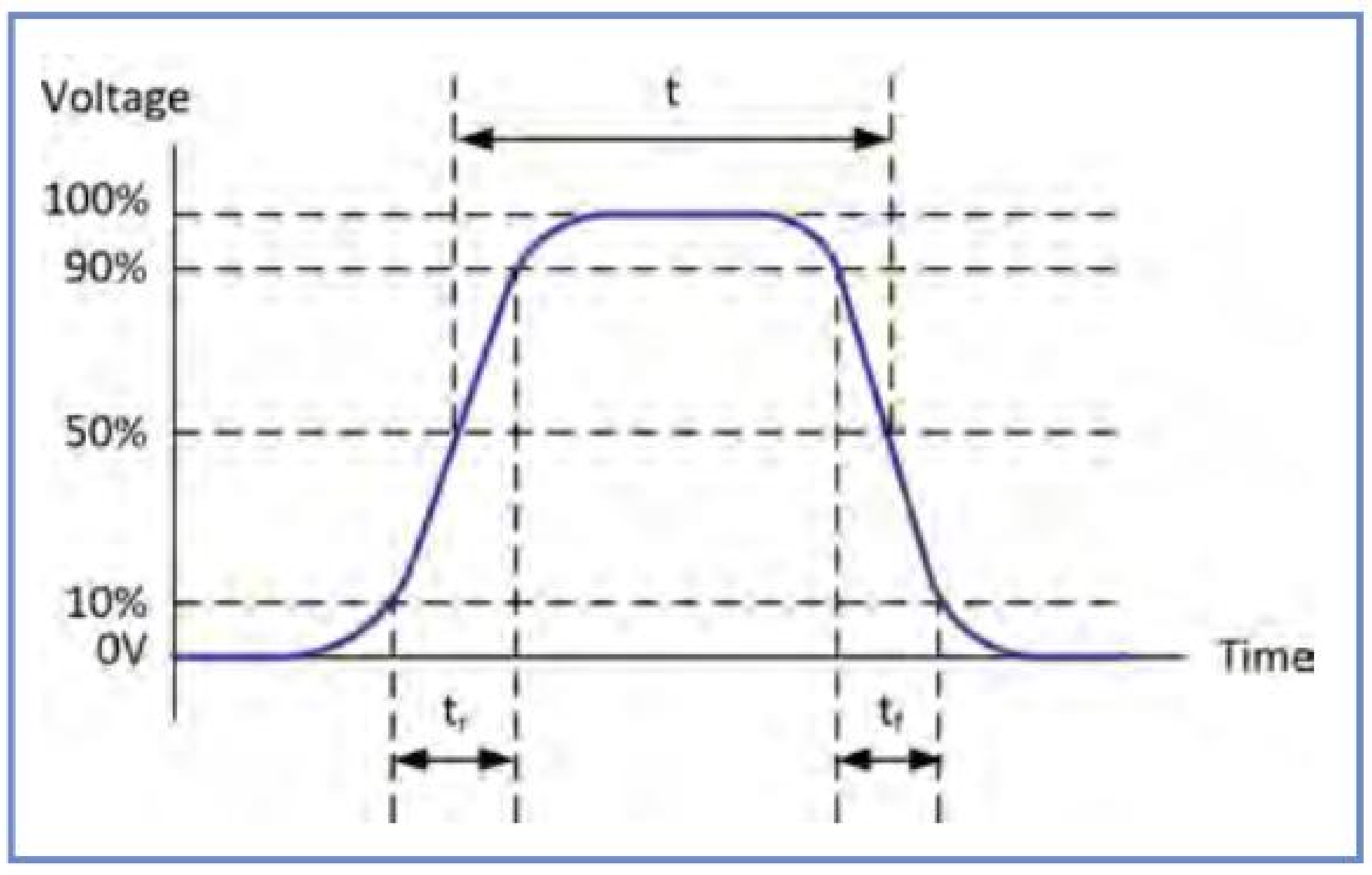


Fig.2.6. Basic parameters of a pulse

the amplitude (or peak value) of the waveform is simply its maximum displacement from zero. It is often more convenient to measure the total excursion of the waveform from its negative peak to its positive peak. With a symmetrical waveform, this peak-to-peak value will be twice the peak value or twice the amplitude. With rectangular or square waveforms, we often just measure the displacement from zero (0V) to the most positive point on the waveform and refer to this as its amplitude or peak value, as shown in Fig.2.5(b).

Pulse measurements

Pulse waveform parameters are shown in Fig.2.6. Here we are usually concerned with the pulse width (*t*) measured at the 50% amplitude level, and the rise and fall times of the pulse. The rise-time (t_{rise}) is the time measured between the 10% and 90% points on the rising (or positive-going) edge of the pulse. The fall-time (t_{fall}) is the time measured between the 90% and 10% points on the falling (or negative-going) edge of the pulse.

Bandwidth

The approximate bandwidth required to display different types of signals with reasonable precision is given in Table 2.1 (note that this applies equally to other types of scope). The general rule is that for sinusoidal signals the bandwidth should ideally be at least double that of the highest signal frequency, while for square waves and pulse signals the bandwidth should be at least ten times that of the highest signal frequency. It is worth noting that most manufacturers define the bandwidth of an instrument as the frequency at which a sinewave input signal will fall to 0.707 of its true amplitude (ie, the –3dB point). To put this into context, when a measurement is made at the cut-off frequency the indication will be incorrect by a whopping 29%!

Table 2.1 Signals and required bandwidths

Signal	Bandwidth required (approx.)
Low-frequency and power	DC to 10kHz
Audio frequency (general)	DC to 20kHz
Audio frequency (high-quality)	DC to 50kHz
Square and pulse waveforms (up to 5kHz)	DC to 100kHz
Fast pulses with small rise-times	DC to 1MHz
Video	DC to 10MHz
Radio (LF, MF and HF)	DC to 50MHz

Digital storage oscilloscopes (DSO)

The simplified block schematic diagram of a typical USB DSO is shown in Fig.2.7. It is worth comparing this with the arrangement of an analogue CRT-based scope shown earlier. The two input channels (Channel 1, or A, and Channel 2, or B) are fed via a high-impedance JFET amplifier to a multiplexer that allows the two input signals to be combined in various ways (A, B, A + B, A – B).

The analogue output of the two multiplexers is fed to a variable-gain amplifier and from there, via a low-pass filter (LPF) to a dual high-speed analogue-to-digital converter (ADC). The multi-bit digitally encoded output of the ADC is then fed to a field-programmable gate array (FPGA). This high-speed application-specific integrated circuit (ASIC) provides the necessary hardware logic to process the sampled digital signals and store them in static random access memory (SRAM). The captured data is also made accessible to the CPU, which provides further signal processing as well as the ability to accept commands via the keyboard interface and output data for display on the LCD panel. A USB interface is also provided for connection to an external computer for data logging and further data analysis.

Additional DSO functions

Thanks to the processing power available, coupled with mass storage capability, a computer-based DSO can provide a variety of additional functions, such as spectrum analysis and digital display of both frequency and voltage. In addition,

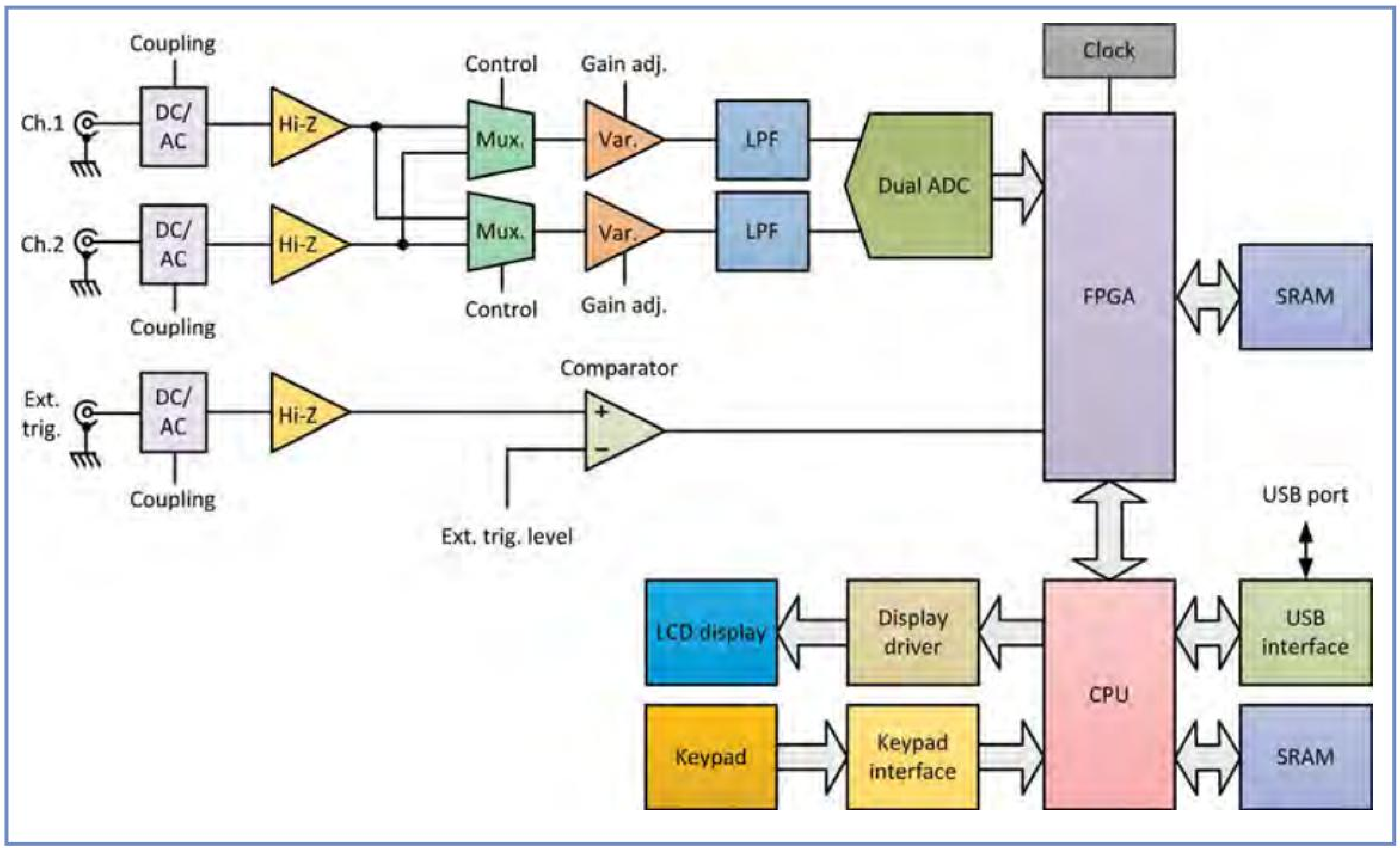


Fig.2.7. Simplified block schematic of a typical USB DSO

LabNation
A
B
AUX

Fig.2.8. High-performance dual-channel USB DSO with a sampling rate of 2 × 100M samples per second. SmartScope can be used with a wide range of operating systems, currently including Windows, Linux, OS X, Android and iOS

Get it right when using an analogue oscilloscope!

- Avoid setting the brightness too high or leaving a single bright spot on the screen because this can damage the CRT's internal phosphor coating
- Check that you have all variable controls set to the 'CAL' position before attempting to make accurate measurements
- Check that you have the correct trigger selected for the type of waveform under investigation
- Before taking DC offset measurements, remember to align the trace for 0V with the input selector set to 'GND'
- Use the built-in calibrator facility to check the accuracy of the attenuator and the 'CAL' setting of the variable gain control. If your scope doesn't have an internal calibration facility then build this month's *Test Gear Project* – see page 42
- Always use a purpose-designed scope probe and check that you have a proper connection to ground or 0V before taking any measurements
- Don't rely on voltage measurements on circuits where high-frequency signals may be outside the bandwidth of the scope
- Avoid placing the oscilloscope where there are strong local magnetic fields as they may cause unwanted deflection of the electron beam.

the ability to save waveforms and measurements for future analysis or for comparison purposes can be extremely valuable, particularly where evidence of conformance with standards or specifications is required.

The additional functions generally available from a DSO include:

- Digital display of voltage
- Digital display of frequency and/or periodic time
- Frequency spectrum display and analysis
- Data logging (ie, storage of waveform data for later analysis)
- Ability to save/print waveforms and other relevant information.

Types of DSO

Various types of DSO are available, including stand-alone instruments fitted with LCD displays and USB instruments that make use of a computer loaded with appropriate software. The DSO software is usually supplied on CD-ROM or can be downloaded from the manufacturer's website. It is important to note that although the DSO hardware cannot usually be used without the appropriate software, some manufacturers can supply software drivers that will allow you to control the DSO and capture data into your own applications. However, for most of us this isn't an option since the supplied software will usually outperform anything that we can write ourselves!

A DSO combines elements of both hardware and software. These must work together to provide not only the functionality of a conventional DSO, but also a spectrum analyser, data logger, digital frequency meter and voltmeter. In many cases a DSO will be able to replace several items of conventional test equipment. Switching between these instruments is usually quick and easy, and in most cases each instrument can have a dedicated window on the PC display. Multiple views of the same signals and on-screen display voltage and frequency can greatly enhance measurements made with a DSO. In addition, some DSO waveforms can be annotated with notes and they can subsequently be printed, saved or exported to other applications.

Speed and resolution

DSO are often classified according to their speed and resolution. A high-speed DSO is designed for examining waveforms that are rapidly changing but such an instrument does not necessarily provide high-resolution measurement. Similarly, a high-resolution DSO is useful for displaying waveforms with a high degree of precision, but it may not be suitable for examining fast changing waveforms.

The upper signal frequency limit of a DSO is determined primarily by the rate at which it can sample an incoming signal. Typical sampling rates for different types of DSO range from 100K samples per second for a low-cost DSO to well over 100M samples per second for a high-specification instrument. To display waveforms with reasonable accuracy it is normally suggested that the sampling rate should be at least twice and preferably more than five times the highest signal frequency. Thus, to display a 10MHz signal with any degree of accuracy a sampling rate of 50M samples per second will be required.

The five-times rule needs a little explanation. When sampling signals in a digital-to-analogue converter we usually apply the Nyquist criterion. This states that the sampling frequency must be at least twice the highest analogue signal frequency. Unfortunately, this no longer applies in the case of a DSO where we need to sample at an even faster rate to accurately display the signal. In practice, we would need a minimum of about five points within a single cycle of a sampled waveform in order to reproduce it with approximate fidelity. Hence, to ensure accuracy, the sampling rate should be at least five times that of highest signal frequency.

Resolution and accuracy

The relationship between resolution and signal accuracy (not bandwidth) is simply that the more bits used in the conversion process the more discrete voltage levels can be resolved by the DSO. The relationship is as follows:

$x = 2^n$

where x is the number of discrete voltage levels and n is the number of bits. Thus,

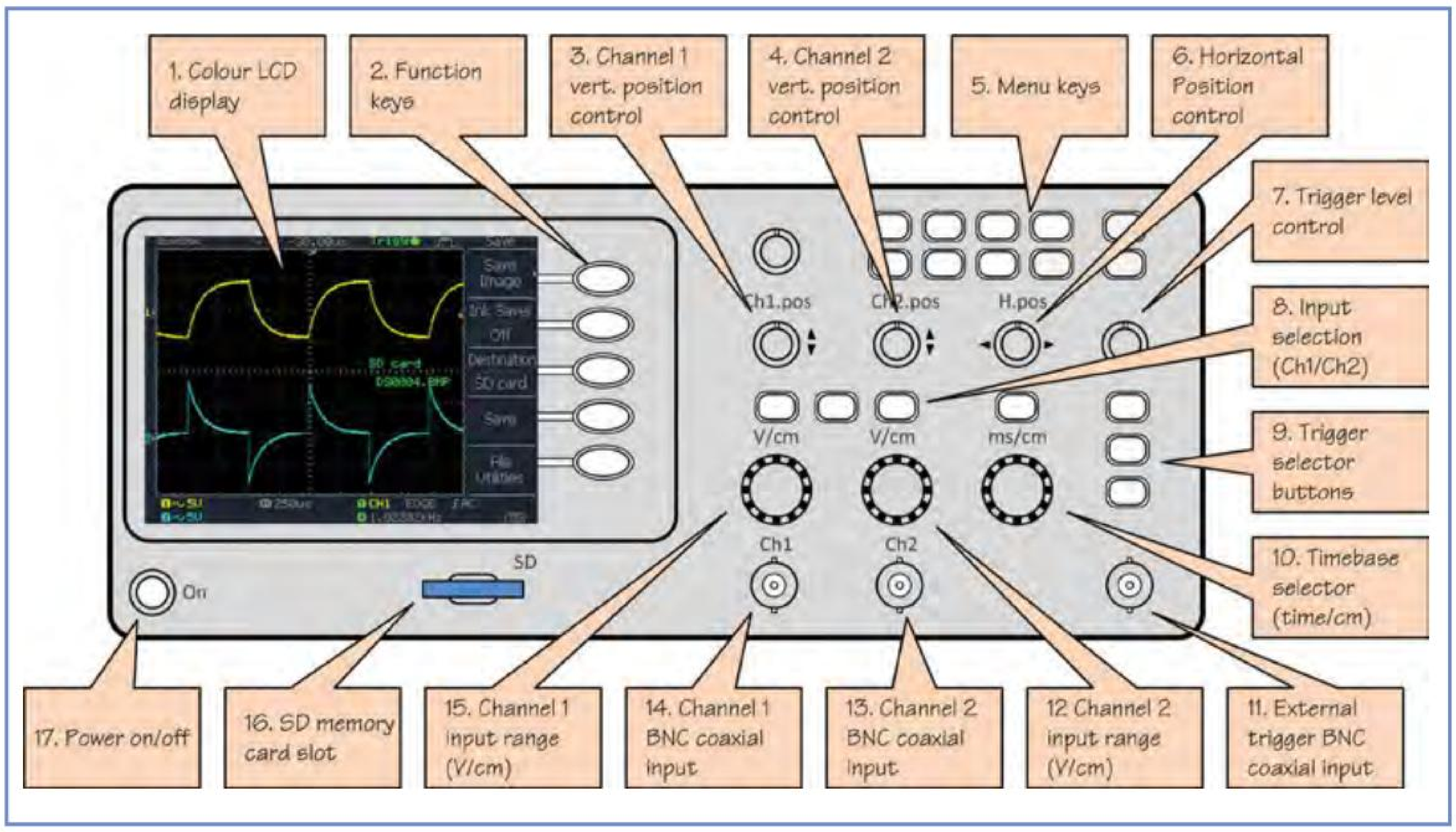

1. Colour LCD display
2. Function keys
3. Channel 1 vert. position control
4. Channel 2 vert. position control
5. Menu keys
6. Horizontal Position control
7. Trigger level control
8. Input selection (Ch1/Ch2)
9. Trigger selector buttons
10. Timebase selector (time/cm)
11. External trigger BNC coaxial input
12 Channel 2 input range (V/cm)
13. Channel 2 BNC coaxial input
14. Channel 1 BNC coaxial input
15. Channel 1 input range (V/cm)
16. SD memory card slot
17. Power on/off
Ch1.pos
Ch2.pos
H.pos
V/cm
V/cm
ms/cm
Ch1
Ch2
SD
On

Fig.2.9. The controls and adjustments available on a typical mid-range stand-alone DSO

Table 2.2 Relationship between the number of bits and resolution

Number of bits, *n*	Number of discrete voltage levels, *x*
8	256
10	1024
12	4096
16	65536

each time we use an additional bit in the conversion process we double the resolution of the DSO, as shown in Table 2.2.

Storage

A DSO stores its captured waveform samples in buffer memory. Hence, for a given sampling rate, the size of this memory buffer determines how long the DSO can capture a signal before its buffer memory becomes full. The relationship between sampling rate and buffer memory capacity is important. A DSO with a high sampling rate but small memory will only be able to use its full sampling rate on the top few timebase ranges.

To put this into context, it's worth considering a simple example. Assume that we need to capture 10,000 cycles of a 10MHz square wave. This signal will occur in a time frame of 1ms. If we apply the Nyquist criterion (five-times rule) we would need a bandwidth of at least 50MHz to display this signal accurately.

As mentioned earlier, to faithfully reconstruct the square wave, we would need a minimum of about five samples per cycle so a minimum sampling rate would be 5 x 10MHz = 50M samples per second. To capture data at the rate of 50M samples per second for a time interval of 1ms requires a memory that can store 50,000 samples. If each sample uses 16-bits we would require 100kbyte of extremely fast memory!

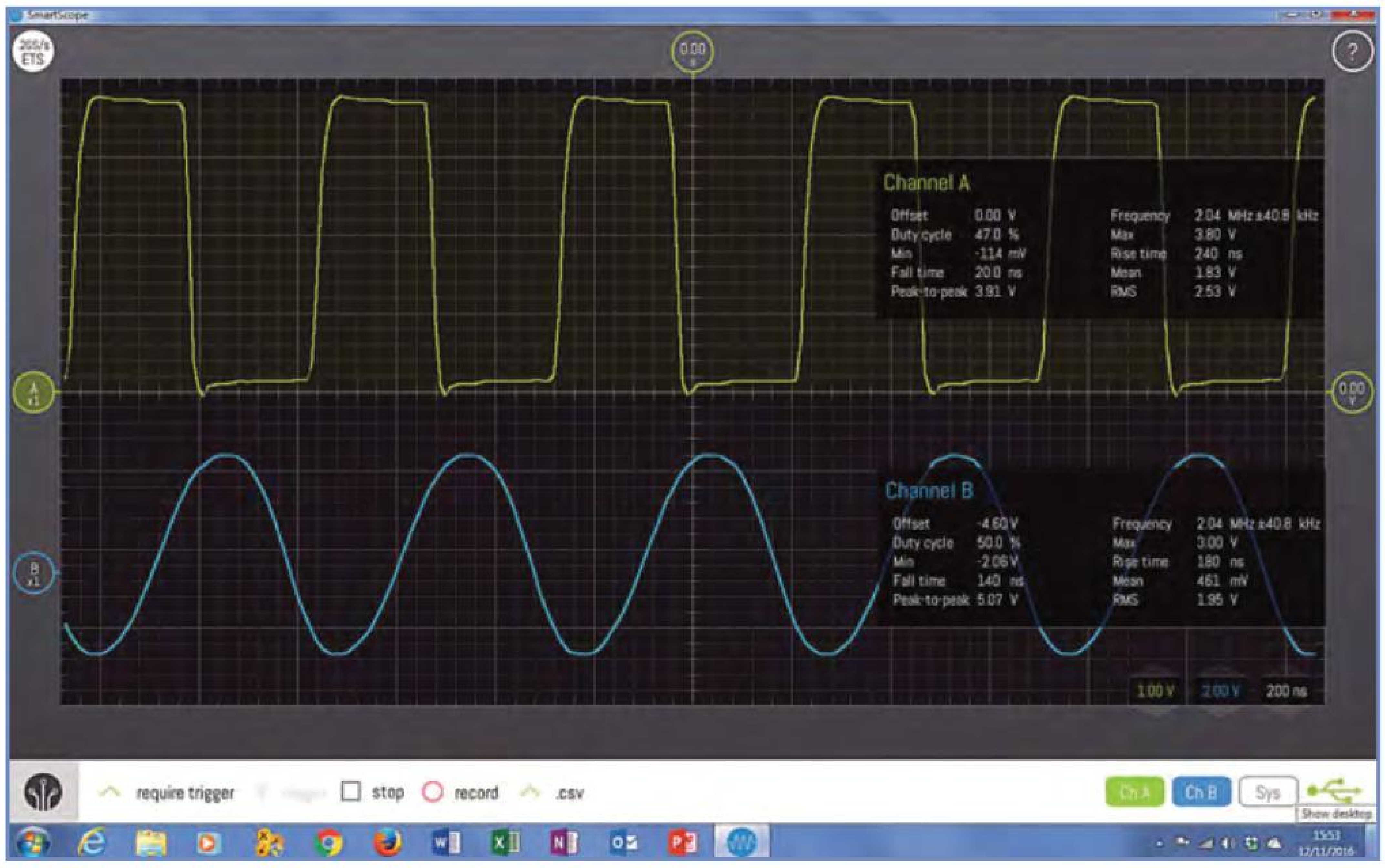
The measurement resolution of a DSO (in terms of the smallest voltage change that can be measured) depends on the actual range that is selected. So, for example, on the 1V range an 8-bit DSO can detect a voltage change of 1/256 of a volt, or about 4mV. For most measurement applications, this will prove to be perfectly adequate as it amounts to an accuracy of about 0.4% of full-scale.

Using a stand-alone DSO

In Fig.2.4 we've summarised the controls and adjustments found on a typical mid-range stand-alone DSO. As with a CRT-based scope, it is worth getting to know your instrument beccause this will allow you to get the very best out of it. Once again, the procedure and adjustments differ according to the type of waveform being investigated and whether the oscilloscope is being used to display a single waveform (single-channel operation) or display several waveforms simultaneously (multi-channel operation).

Get it right when using a digital oscilloscope!

- When observing high-frequency and pulse waveforms ensure that the DSO can sample at a sufficiently fast rate
- Be aware of the Nyquist criterion and how this can affect waveform displays
- Check that you have the correct trigger selected for the type of waveform under investigation
- Before taking DC offset measurements, remember to align the trace for 0V with the input selector set to 'GND'
- Be aware of the relationship between sampling rate and the available buffer memory (a large sample may overflow the available memory)
- Always use a purpose-designed scope probe. Check that you have an effective ground connection before taking any measurements and ensure that the probe's compensation is checked (and adjusted, if necessary) on a regular basis.



Channel A

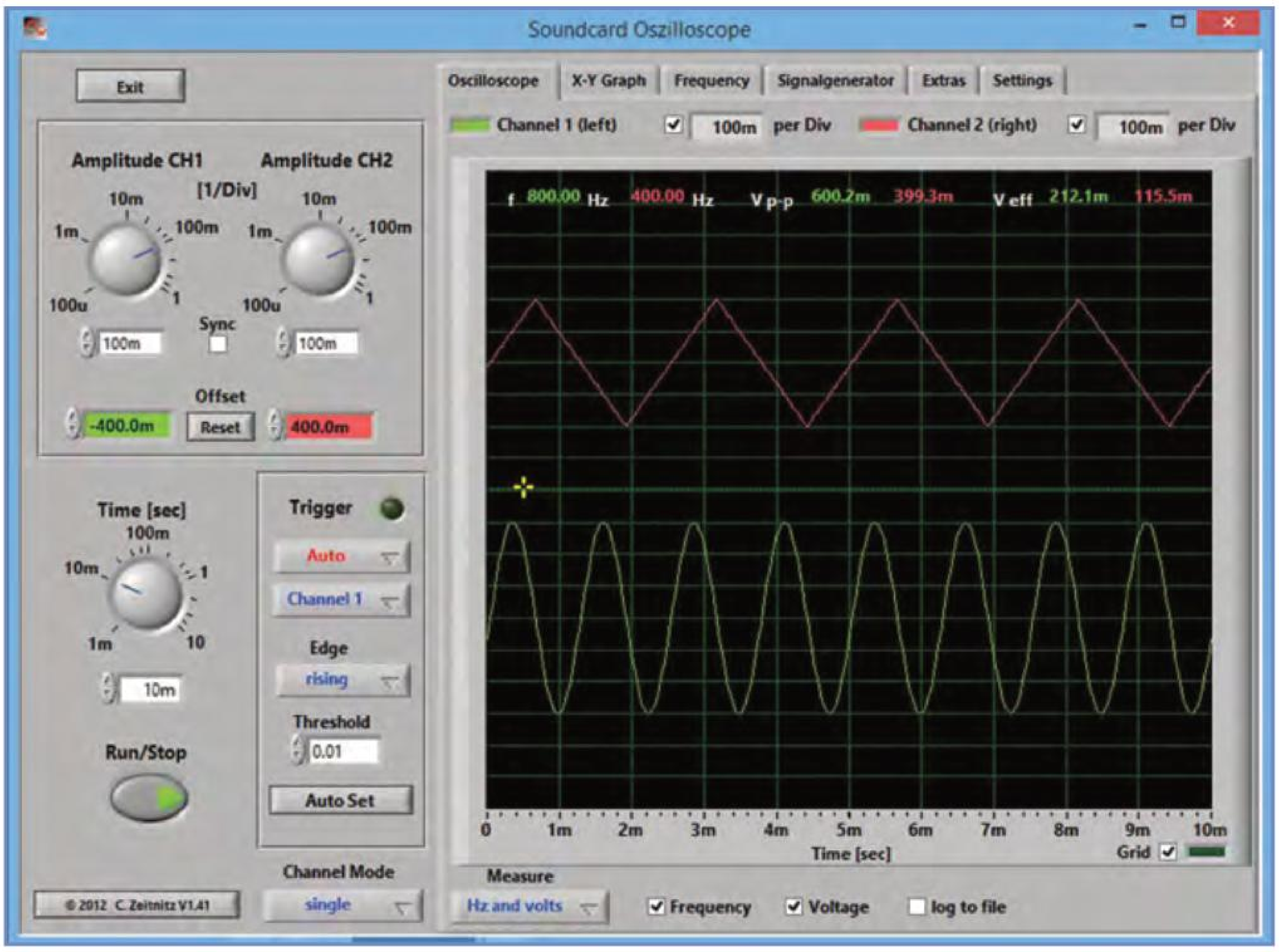
Offset 0.00 V
Duty cycle 47.0 %
Min -114 mV
Fall time 20.0 ns
Peak-to-peak 3.91 V
Frequency 2.04 MHz ±40.8 kHz
Max 3.80 V
Rise time 240 ns
Mean 1.83 V
RMS 2.53 V

Channel B

Offset -4.60 V
Duty cycle 50.0 %
Min -2.06 V
Fall time 140 ns
Peak-to-peak 5.07 V
Frequency 2.04 MHz ±40.8 kHz
Max 3.00 V
Rise time 180 ns
Mean 461 mV
RMS 1.95 V

Fig.2.10. Typical USB DSO display from a Windows-based desktop PC. Channel A shows a 2MHz square wave with rise and fall times of 24ns and 20ns respectively, while Channel B shows a 2MHz 5V peak-peak sinewave

Many of the controls present in a DSO have direct equivalents in a CRT-based instrument. Others, such as menu selection and function keys are unique to the DSO. The usual input and trigger selectors are present, as is the trigger-level control. Just like a CRT-based instrument, the timebase control is marked in terms of 'time per division', however it may also be possible to configure a DSO in terms of 'time per scan', which may make more sense when making some measurements.



Soundcard Oscilloscope

Channel 1 (left) ☑ 100m per Div
Channel 2 (right) ☑ 100m per Div

f 800.00 Hz 400.00 Hz
V p-p 600.2m 399.3m
V eff 212.1m 115.5m

Amplitude CH1 100m
Amplitude CH2 100m
Offset -400.0m 400.0m
Time [sec] 10m
Trigger Auto
Channel 1
Edge rising
Threshold 0.01
Channel Mode single
Measure Hz and volts
☑ Frequency ☑ Voltage ☐ log to file

Fig.2.11. Typical soundcard scope display produced by Christian Zeitnitz's excellent Soundcard Scope software. The display shows low-frequency triangle and sine waveforms (red and green traces respectively)

For multi-channel DSOs you can select which of the channels to display but, unlike a CRT-based analogue scope, each of the two-channel traces can be displayed in a different colour. Voltage ranges are selected in much the same way as for a CRT-based scope, but an auto-ranging facility may also be included. This option can be particularly useful if you need to switch between input signals of widely differing amplitude.

Gearing up: oscilloscopes

For newcomers, choosing an oscilloscope can be a somewhat daunting task. The first step is deciding what you want to use the instrument for, and it's worth asking the following questions:

- What measurements will you be making on a *regular* basis?
- What *additional* measurements might you wish to perform?
- Do you need to measure pulse waveforms accurately or do you usually work with sinusoidal signals?
- Are your signals repetitive or are they one-off single-shot signals?
- Do you need to measure small time intervals, or small signal amplitudes, fast pulses, or high frequency signals?
- Do you need to display frequency spectra as well as time-related voltage waveforms?
- Will the scope only be used on the bench or will it be used as an item of portable test equipment?
- What budget is available for purchasing an instrument?

It's likely that your choice might fall into one of these five categories:

1. A low-cost self-contained DSO. This is a good choice if you only need to carry out basic everyday measurements at frequencies up to about 50MHz. When compared with an analogue oscilloscope, a DSO will also provide you with some useful additional features. You can expect to pay around £250 for a basic two channel instrument with a 70MHz bandwidth and an 800 × 480 display. Mini hand-held instruments are also available at well under £200, but they usually have inferior specification and a limited display size.
2. A high-speed/high-resolution DSO. This could be a more expensive solution but it is one that should cope with your medium and long-term needs. In many cases you may find that you are faced with a compromise between resolution and speed. However, a DSO with a 12-bit resolution and sampling rate of 5G samples per second will be more than adequate for most applications. If you don't need this level of performance then an instrument with a 100MHz bandwidth and 8-bit resolution operating at 1G samples should suffice. Expect to pay up to about £500 for such an instrument. As mentioned earlier, it is wise to purchase a DSO with a bandwidth that is five-times higher than the maximum frequency signal you wish to measure. Note, however, that with some instruments the specified bandwidth is not available on *all* voltage ranges, so it is worth checking the manufacturer's specification very carefully.

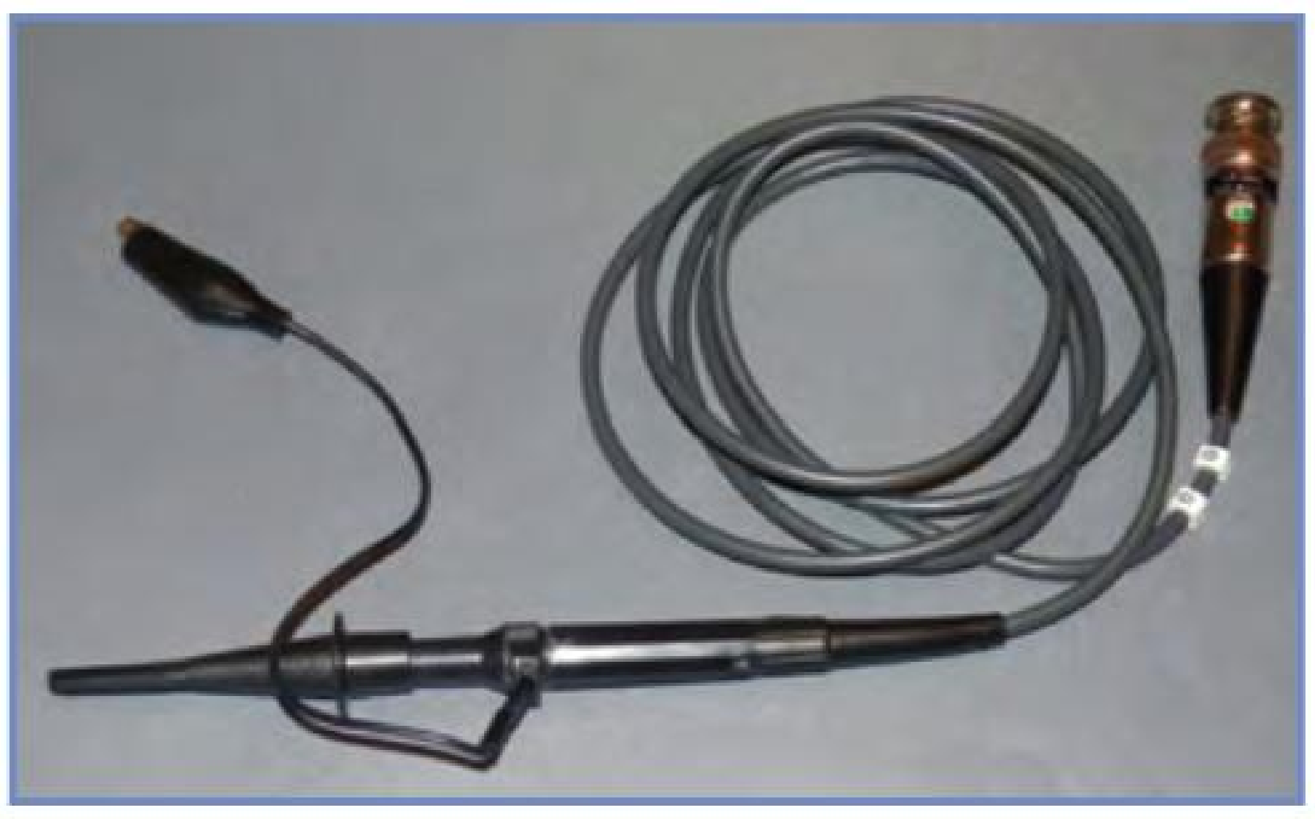


Fig.2.12. Typical x1 and x10 scope probe

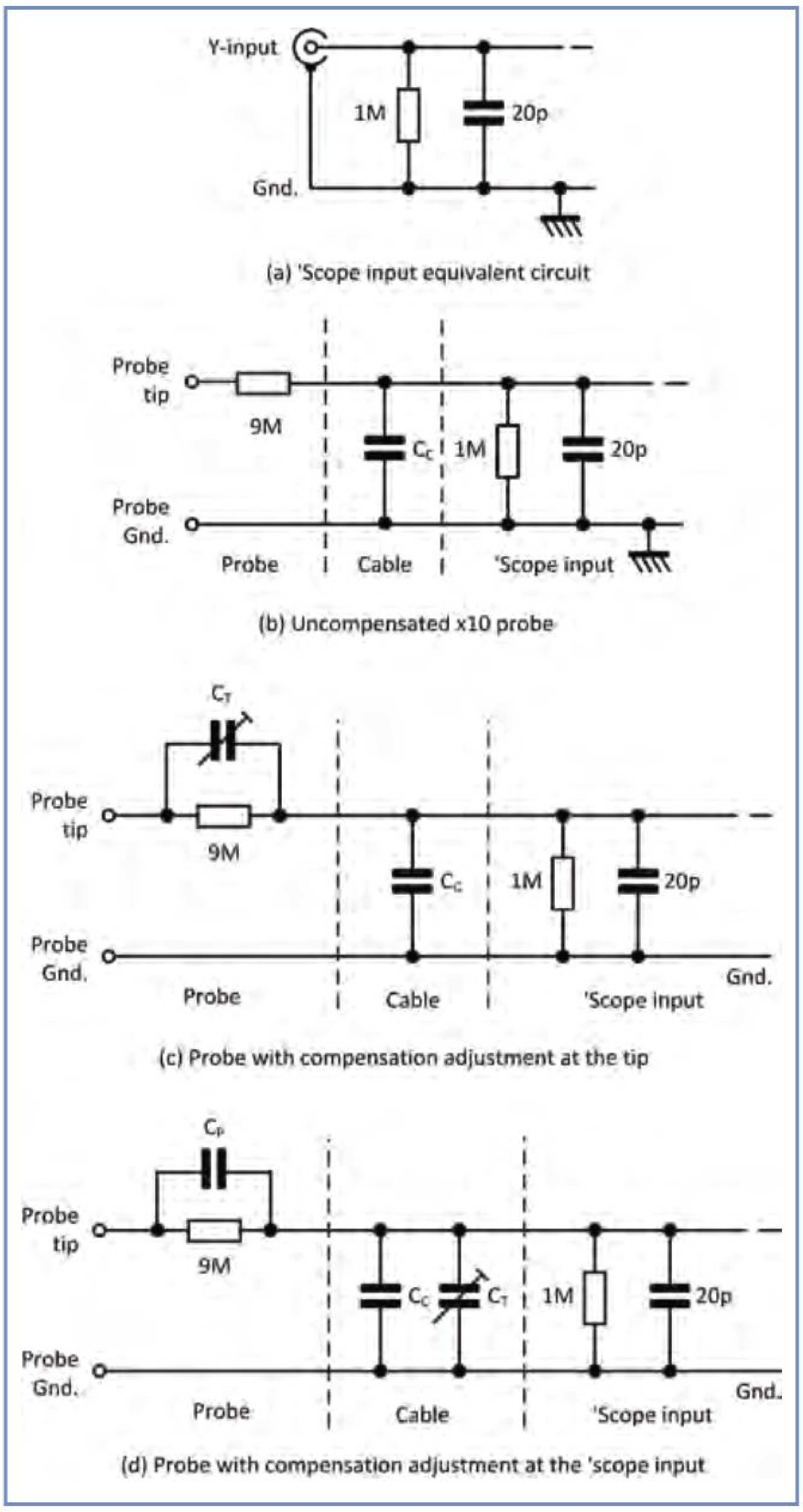


Fig.2.13. Scope probe compensation

3. A mid-range CRT-based analogue scope such as a second-hand Tektronix 2455 can make an excellent investment. With four channels and 150MHz bandwidth such instruments will outperform a low-cost DSO and often for much less money. Instruments from other reputable manufacturers like Philips and Hameg are regularly available from various on-line sources and used-equipment suppliers at very attractive prices. Expect to pay between £50 for a basic 20MHz analogue instrument and (up to) £300 for a high-performance 100MHz scope in good condition. If you plan to spend more than this it might be worth looking at a modern DSO offering similar performance for around the same price.
4. A PC soundcard-based scope. If you only need to display audio frequency waveforms over a limited frequency range (100Hz to 10kHz) this can be an effective low-cost solution. A high-performance soundcard with a fast sampling rate will give better results, but if you need to make accurate voltage measurements you will need to have a means of calibrating the scope (see this month's *Test Gear Project*). You should also note that, while this will work for repetitive waveforms, triggering can be difficult when displaying irregular waveforms and pulses. Measurements of rise- and fall-times will almost certainly be wildly inaccurate. The input impedance offered by a soundcard will typically be around 50kΩ and this is much lower than the standard 1MΩ associated with conventional scopes.
5. An external USB ADC used with a tablet, laptop or bench PC. If you are on a budget but still need to make a wide range of measurements this can be a great solution. It will also give you greater flexibility, allowing you to use the scope with different PCs. For example, a laptop for portable measurements and a desktop PC when in the workshop or lab. The performance of many USB scopes can rival those of a self-contained DSO and often for a significantly lower outlay. Low-cost instruments from Pico, Virtins and Hantek are available at prices ranging from around £50 to a little over £200.

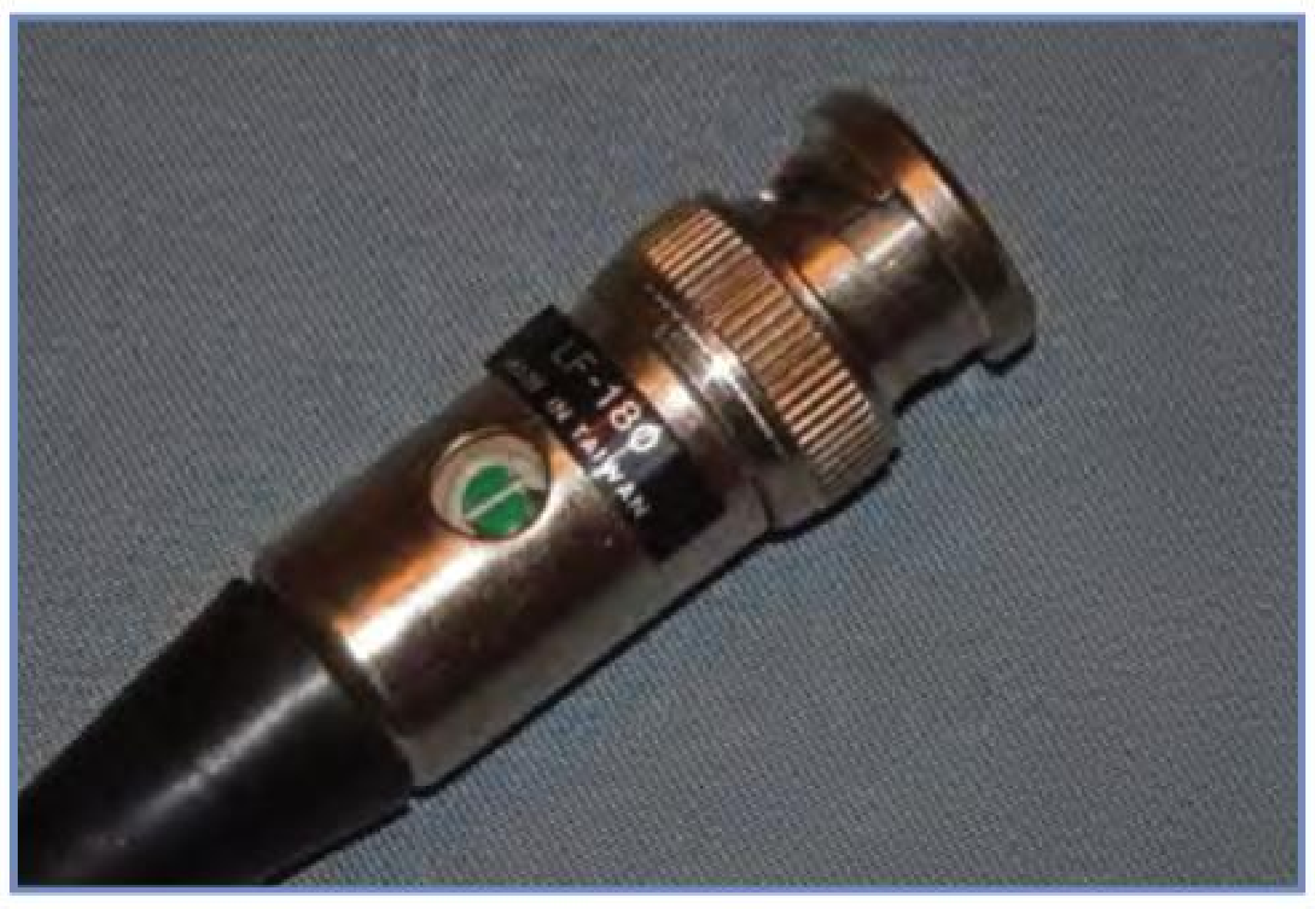


Fig.2.14. Probe compensation adjustment

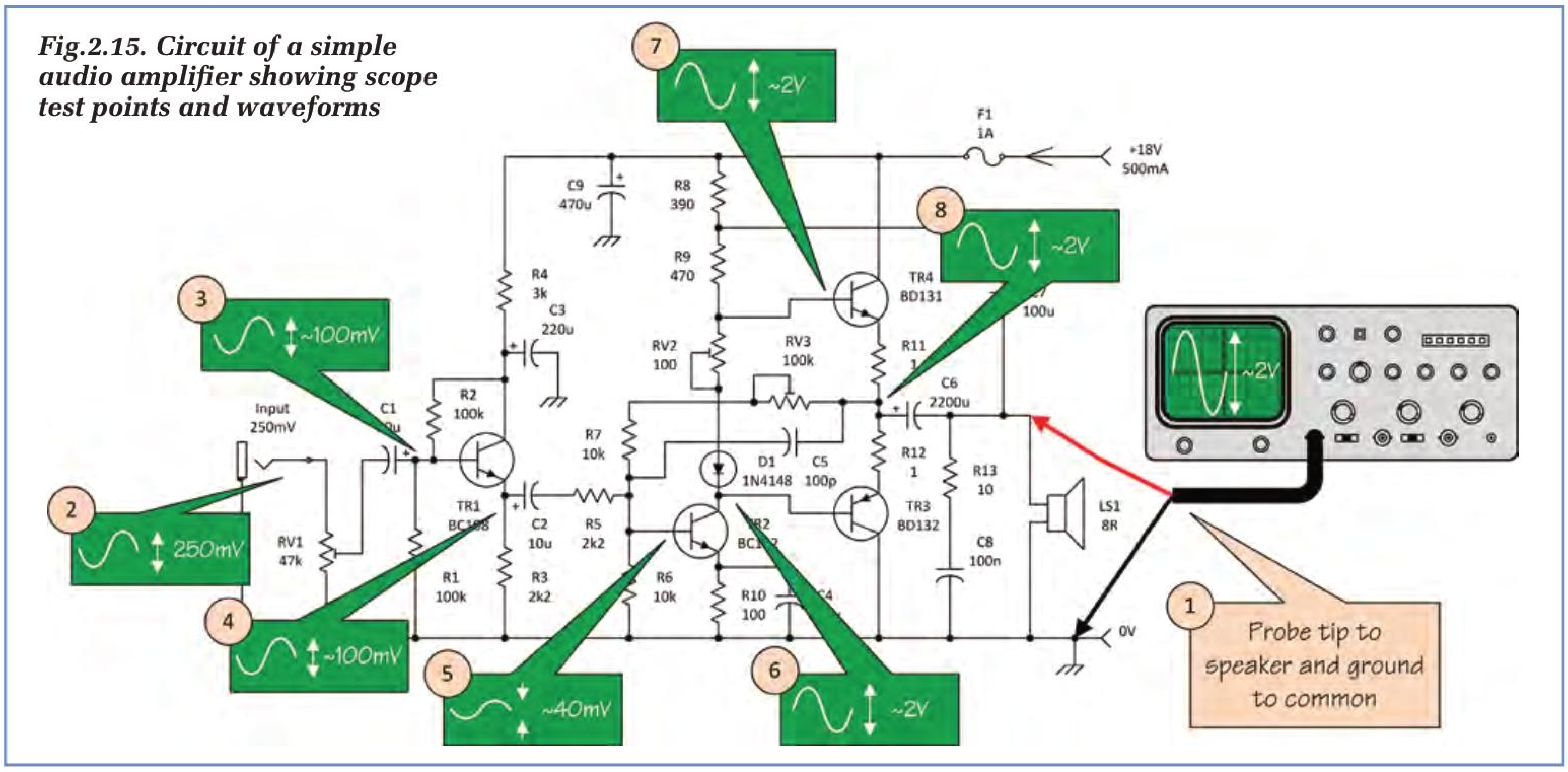


Fig.2.15. Circuit of a simple audio amplifier showing scope test points and waveforms

Scope probes

Earlier, we mentioned the importance of using a purpose-designed scope probe when taking accurate measurements. If your scope doesn't come with a set of probes it is well worth acquiring one or more switchable ×1 and ×10 probes (see Fig.2.12). Note that a '×10' probe provides an *attenuation* of 10 times.

An important requirement of a scope is that it should faithfully reproduce signals and pulses of fast duration and that it should not load the circuit to which it is connected. The standard input resistance of most scopes is 1MΩ, but in parallel with this is a small (stray) capacitance of around 20pF, as shown in Fig.2.13(a). Note that this shunt capacitance also appears in parallel with that of an input cable and this can be appreciable (a typical 50Ω coaxial cable has a capacitance of around 100pF per metre).

Fig.2.13(b) shows the basic arrangement of an uncompensated ×10 probe. A close-tolerance series resistor of 9MΩ forms an attenuator in conjunction with the scope's 1MΩ input resistance. The probe tip then imposes a load of 10MΩ rather than the 1MΩ of the scope alone. The unfortunate consequence of this arrangement is that the 9MΩ probe tip resistance forms a low-pass filter with the combined capacitance of the cable (C_C) acting in parallel with the nominal 20pF input capacitance of the scope. This severely reduces the high-frequency response of the scope/probe combination.

Compensation

Compensation of a scope probe is simply a matter of ensuring that the probe's attenuation ratio remains the same at all frequencies up to, and including, the upper frequency limit of the scope itself. The probe shown earlier in Fig.2.12 uses compensation to achieve a measurement bandwidth of DC to 40MHz ±1dB when used as a ×10 probe. Note that, when used as a ×1 probe the same probe offers a significantly reduced bandwidth of only DC to 3MHz ±1dB.

Compensation can be achieved in various ways to improve the frequency response. Fig.2.13(c) shows how a low-value trimmer capacitor can be introduced in parallel with the 9MΩ probe tip resistor. This arrangement is used in some commercial probes. An alternative arrangement, shown in Fig.2.13(d), uses a fixed capacitor in parallel with the 9MΩ probe tip input resistor and a shunt-connected trimmer capacitor fitted at the scope input. Fig.2.14 shows how the trimmer adjustment is made accessible in the probe's BNC connector. In either case, after applying a square wave calibrating signal to the probe tip (see this month's *Test Gear Project*) the compensating trimmer is simply adjusted for the best square wave (in other words, a square wave with fast rise and fall times and no overshoot).

Check it out!

To put all of this into context, let's look at how an oscilloscope (analogue or digital) can be used to verify the operation of the audio amplifier shown in Fig.2.15. The circuit operates from an 18V DC supply (not shown in Fig.2.5) The first step should be that of connecting a sinusoidal input signal of appropriate amplitude (250mV peak-peak) and frequency (1kHz) to the input and then checking to see that an output is produced. The amplifier's volume control (RV1) should be set to about mid-position (corresponding to normal operation). Since this is not a particularly critical measurement a ×1 scope probe can be used.

Step 1 – Connect the common ground lead from the scope probe to the amplifier's 0V rail. Connect the tip of the scope probe to the signal terminal of the loudspeaker. Set the scope timebase to 200µs/cm and the input to AC 1V/cm. The display should show a 1kHz sinewave of about 2V peak-peak (an amplitude of 1V).

Step 2 – Having established that we have an output (and even if the output is not as expected) it can be useful to carry out some signal tracing by following the signal from stage to stage as it passes through the amplifier. First, check the input signal by connecting the scope probe tip to the input connector (or to the top of volume control, RV1). At this point the signal should be about 250mV peak-peak.

Step 3 – Next, we will check the signal arriving at the input (base terminal) of the first-stage transistor (TR1). The signal at this point should have a peak-peak value of about 100mV.

Step 4 – The first stage of the amplifier operates as an emitter follower and therefore provides a voltage gain of slightly less than unity. Moving the probe tip to the output (emitter terminal) of Tr1 should produce a signal that is similar to that present at its input. Thus, you would expect a signal of about 100mV peak-peak at this point.

Step 5 – To check the driver stage (TR2) you will first need to transfer the scope probe tip to the input (base terminal) of this transistor. Due to R5 appearing in series with the relatively low input impedance of TR2, the signal at this point will be slightly less than the output from TR1. You should find that the signal level has fallen to about 40mV peak-peak.

Step 6 – The final check on the driver stage is that of checking the output of TR2, which appears at its collector terminal. This should be an amplifier (and phase inverted – see later) version of its input. At this point, the signal should have an amplitude of about 2V peak-peak.

Step 7 and 8 – The signals present at the complementary output stage appear at the base of TR3 (a PNP device) and TR4 (an NPN device). These should be of similar amplitude and the same as the output from the driver stage. Both should be measured at about 2V peak-peak.

Note that we have indicated the phase shift of the signal present in the various stages of the amplifier shown in Fig.2.15. The emitter-follower stages of TR1 and TR3/TR4 produce no phase-shift (in other words, they don't invert the signal) while the common-emitter stage, TR2, produces a phase shift of 180° (in other words, it inverts the signal). We've indicated this phase relationship on the waveforms shown in Fig.2.15, but you will not see this phase shift on an oscilloscope display unless you change the scope's trigger setting. In fact, since we are only interested in the shape and amplitude of the signal there's really no need to be concerned about phase shift. In a later *Teach-In 2018* we will explain why phase shift can be important in some circuits and show how it can be accurately measured.

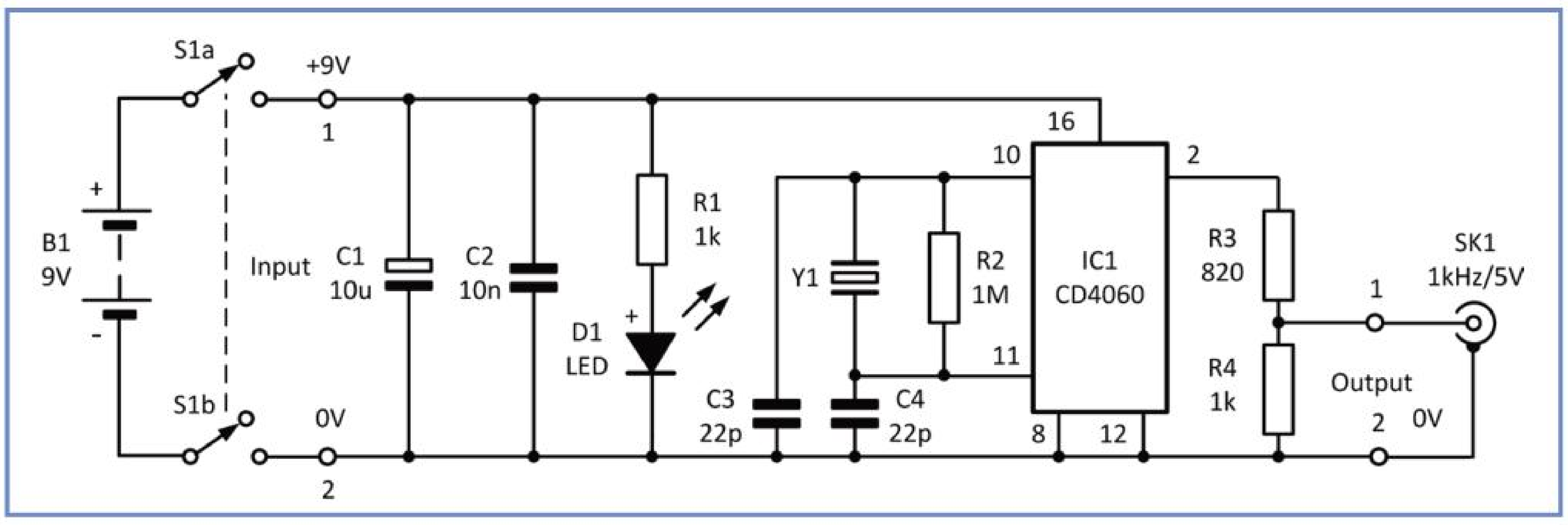


Fig.2.16. Complete circuit of the scope calibrator

Test gear project: handy scope calibrator

It is important to check the calibration of an oscilloscope, particularly if you have any concerns over its accuracy or if you need a signal source for probe calibration. Our second *Test Gear Project* provides an accurate 1kHz square wave signal source with an amplitude of 5V, together with fast rise and fall times. The scope calibrator is small, inexpensive and easily constructed and will typically work to a frequency accuracy better than 0.1% and a voltage accuracy of 5%, or better.

The complete circuit of our *Test Gear Project* is shown in Fig.2.16. The circuit is very simple and uses only a handful of inexpensive components. The circuit is based on a CD4060 14-stage binary counter. This device provides TTL-compatible outputs and operates from a supply voltage of between 3V and 15V. The device features an internal oscillator, which is controlled from an external ceramic resonator or, for improved stability, a quartz crystal.

You will need

Perforated copper stripboard (9 strips, each with 25 holes)
2-way terminal blocks (2)
ABS case with integral battery compartment
9V PP3 battery clip
9V PP3 battery
Miniature DPDT toggle switch (S1)
Panel-mounting BNC connector (SK1)
CD4060 14-stage binary counter (IC1)
8.192MHz HC49S low-profile quartz crystal (Y1)
16-pin low-profile DIL socket
5mm red LED (D1)
1 1kΩ resistor (R1)
1 1MΩ resistor (R2)
1 820Ω resistor (R3)
1 1kΩ resistor (R4)
1 10µF 16V radial lead electrolytic capacitor (C1)
1 10nF ceramic capacitor (C2)
2 22pF ceramic capacitors (C3 and C4).

Assembly

Assembly is straightforward and should follow the layout shown in Fig.2.17. Note that the '+' symbol shown on D1 indicates the more positive (anode) terminal of the LED. The pin connections for the LED is shown in Fig.2.18.

The reverse side of the board (*not* an X-ray view) is also shown in Fig.2.17. Note that there is a total of 29 track breaks to be made. These can be made either with a purpose-designed spot-face cutter or using a small drill bit of appropriate size. There are also nine links that can be made with tinned copper wire of a suitable diameter or gauge (eg, 0.6mm/24SWG). When soldering has been completed it is very important to carry out a careful visual check of the board as well as an examination of the track side of the board looking for solder splashes and unwanted links between tracks.

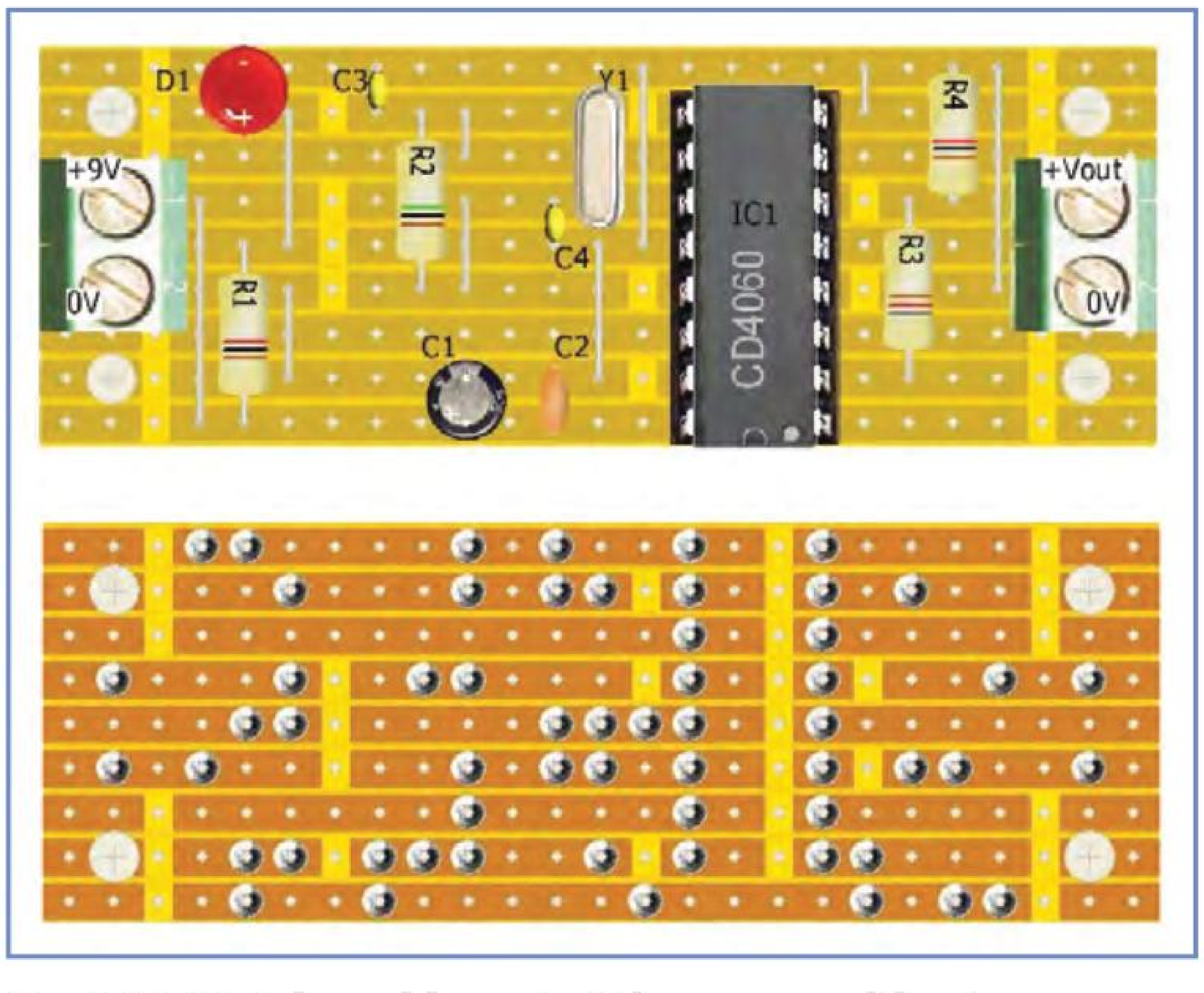


Fig.2.17. Stripboard layout of the scope calibrator

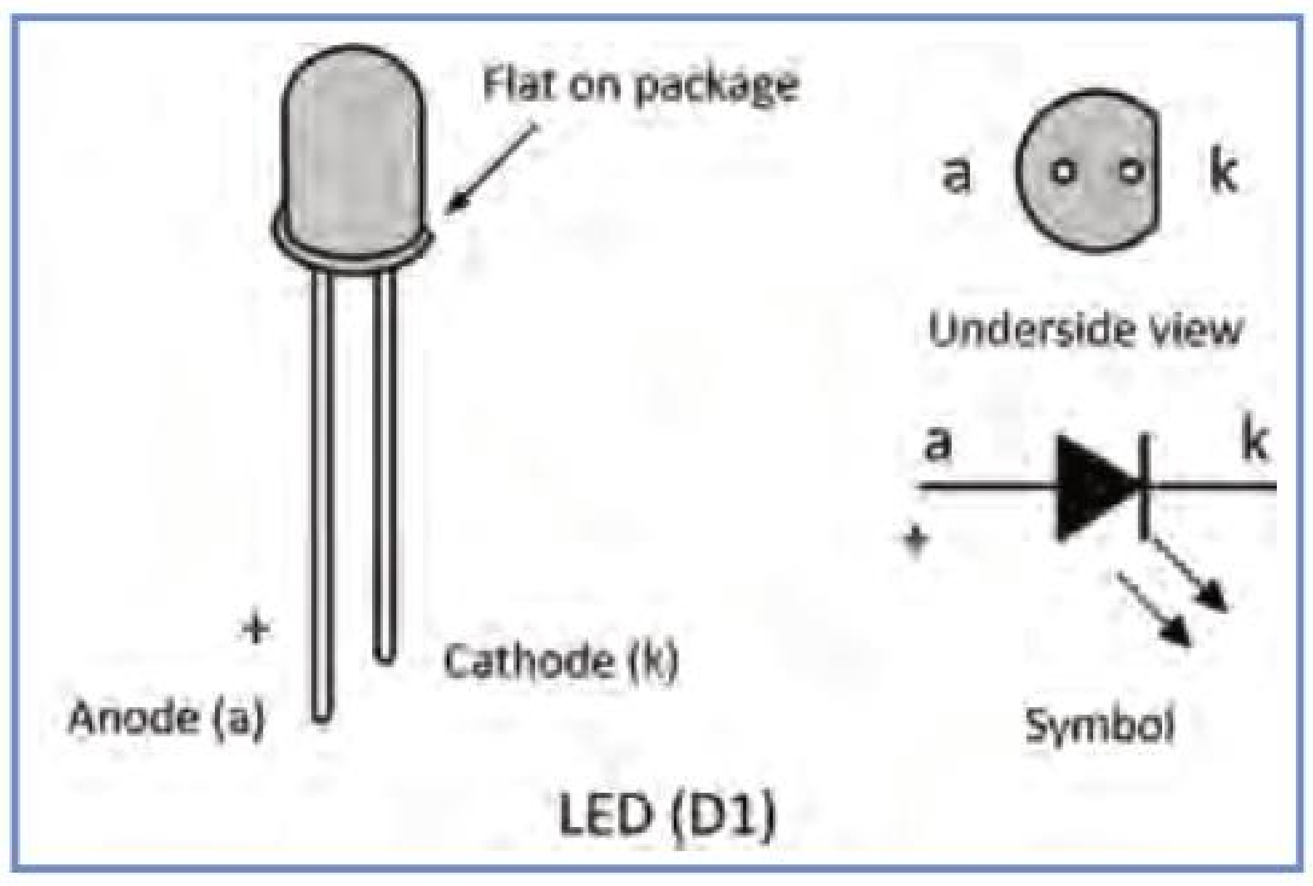


Fig.2.18. LED connections

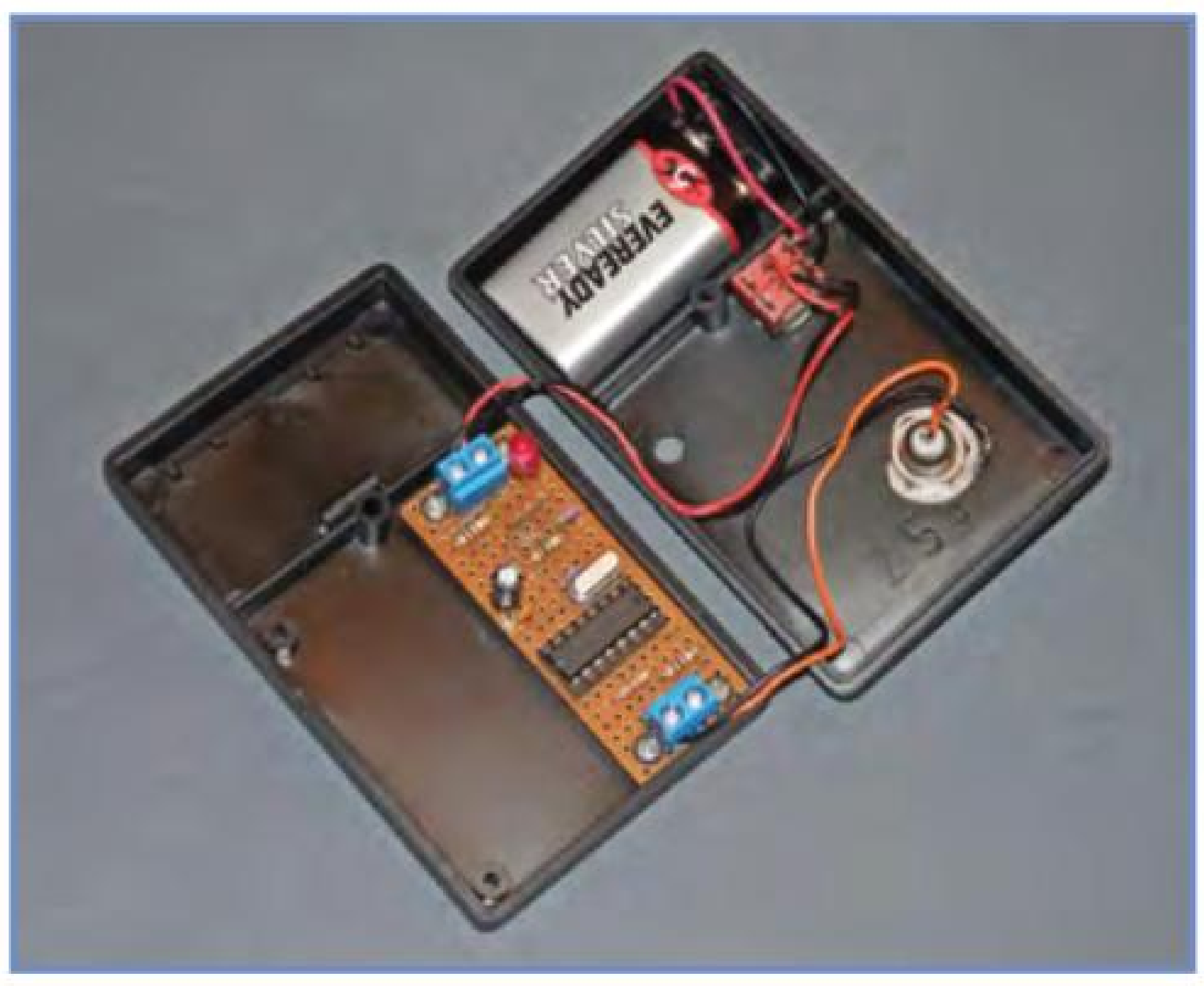


Fig.2.19. Internal wiring of the scope calibrator

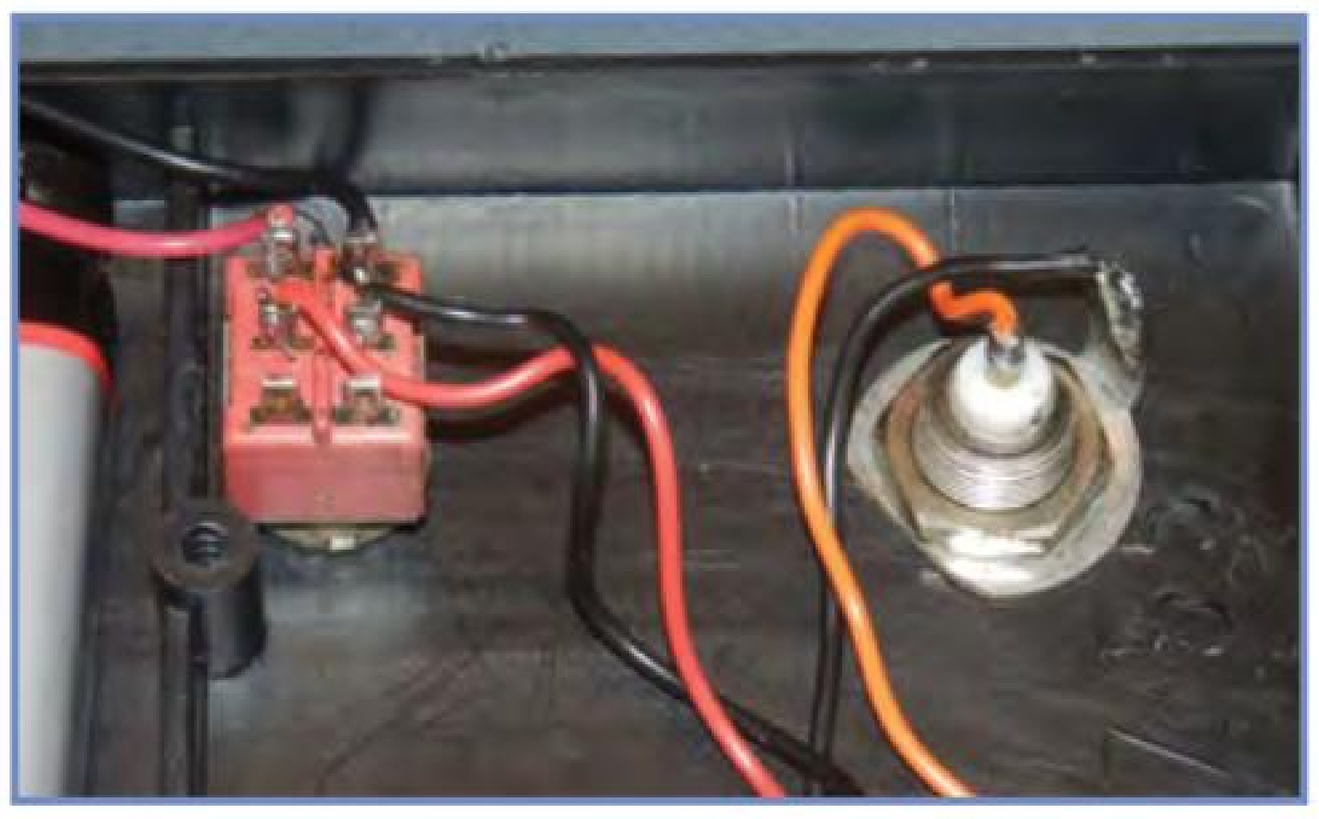


Fig.2.20. Rear panel wiring

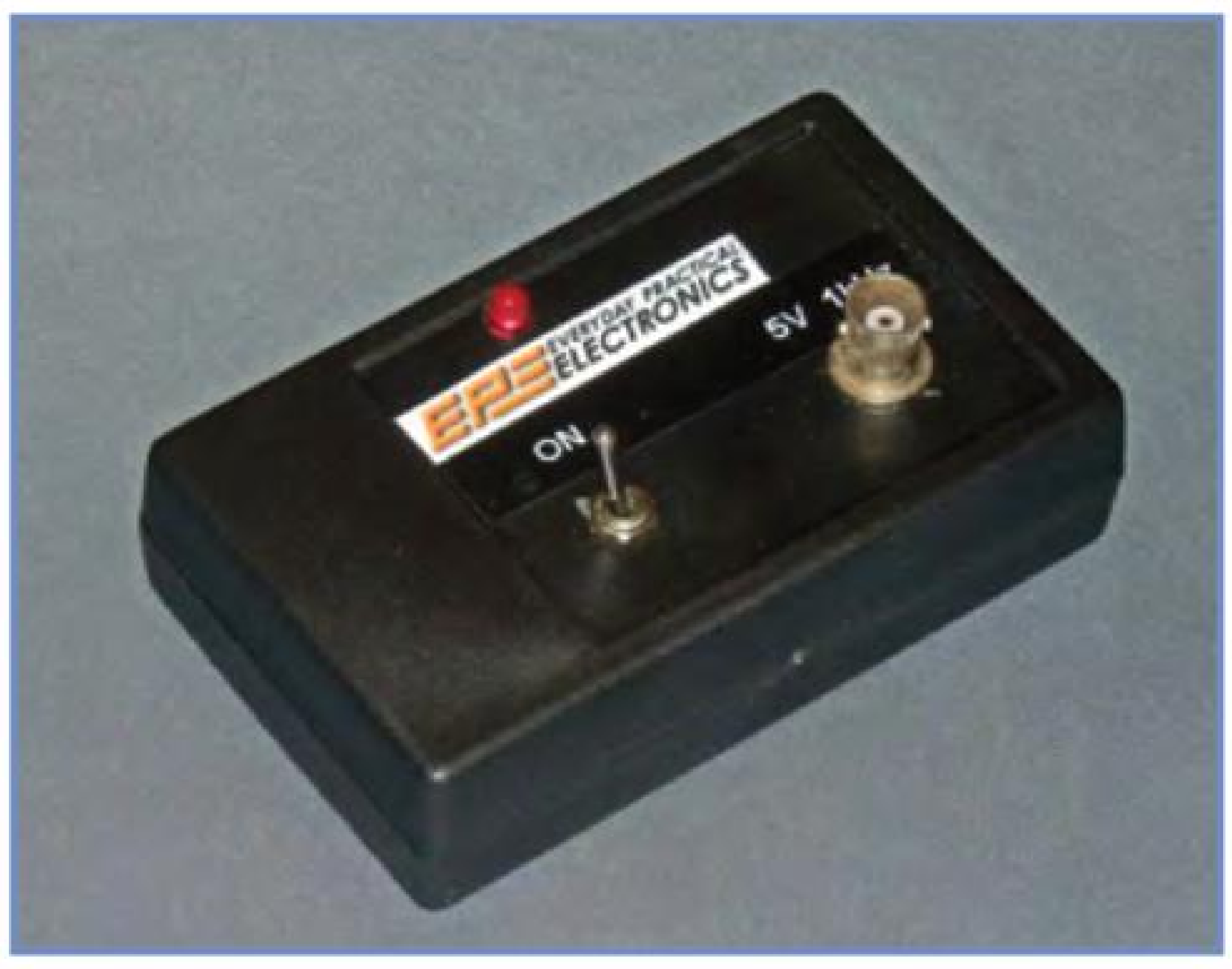


Fig.2.21. External appearance of the finished scope calibrator

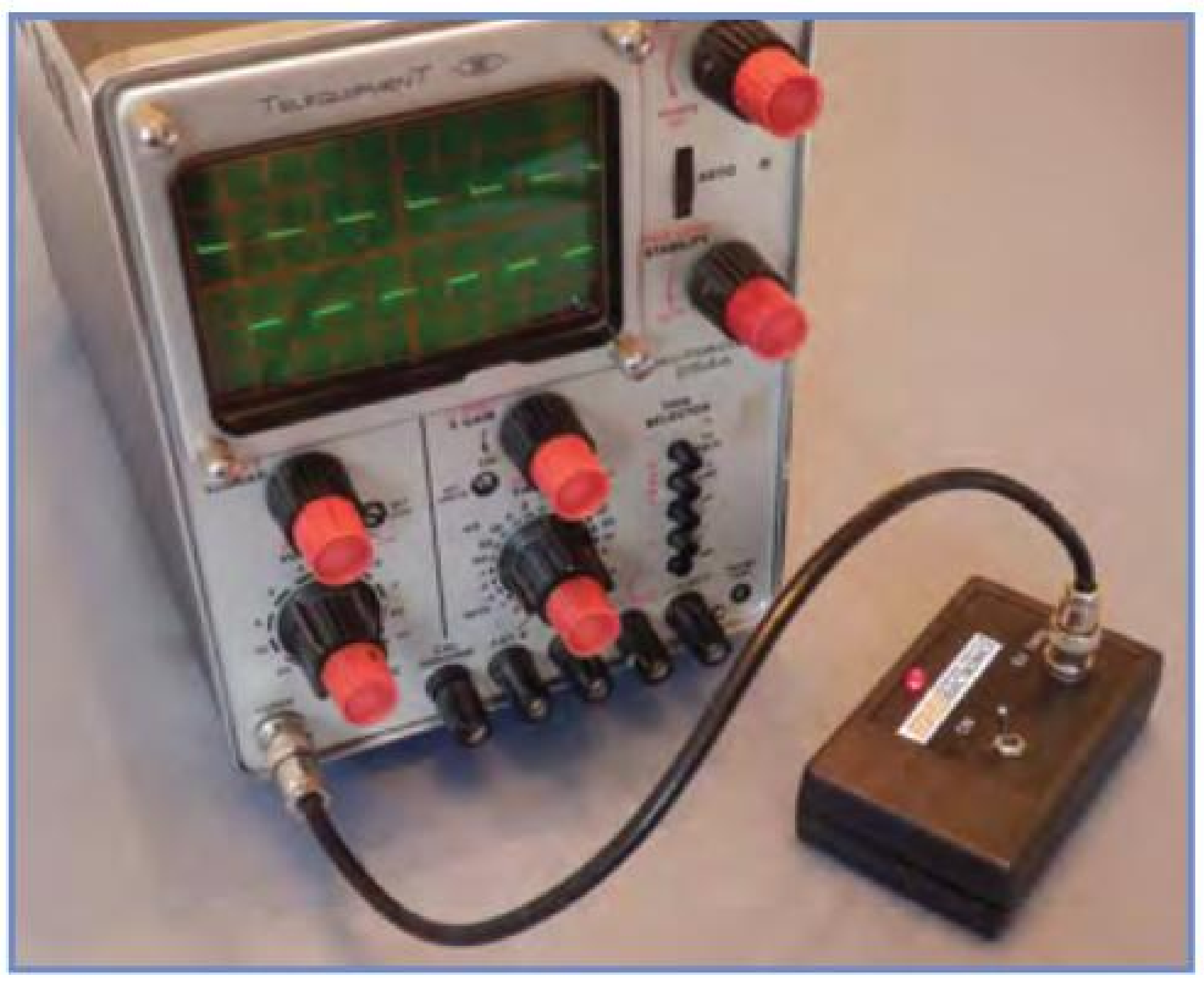


Fig.2.22. Checking an elderly analogue scope (note the slight overshoot indicating the need for adjustment of the internal attenuator compensation)

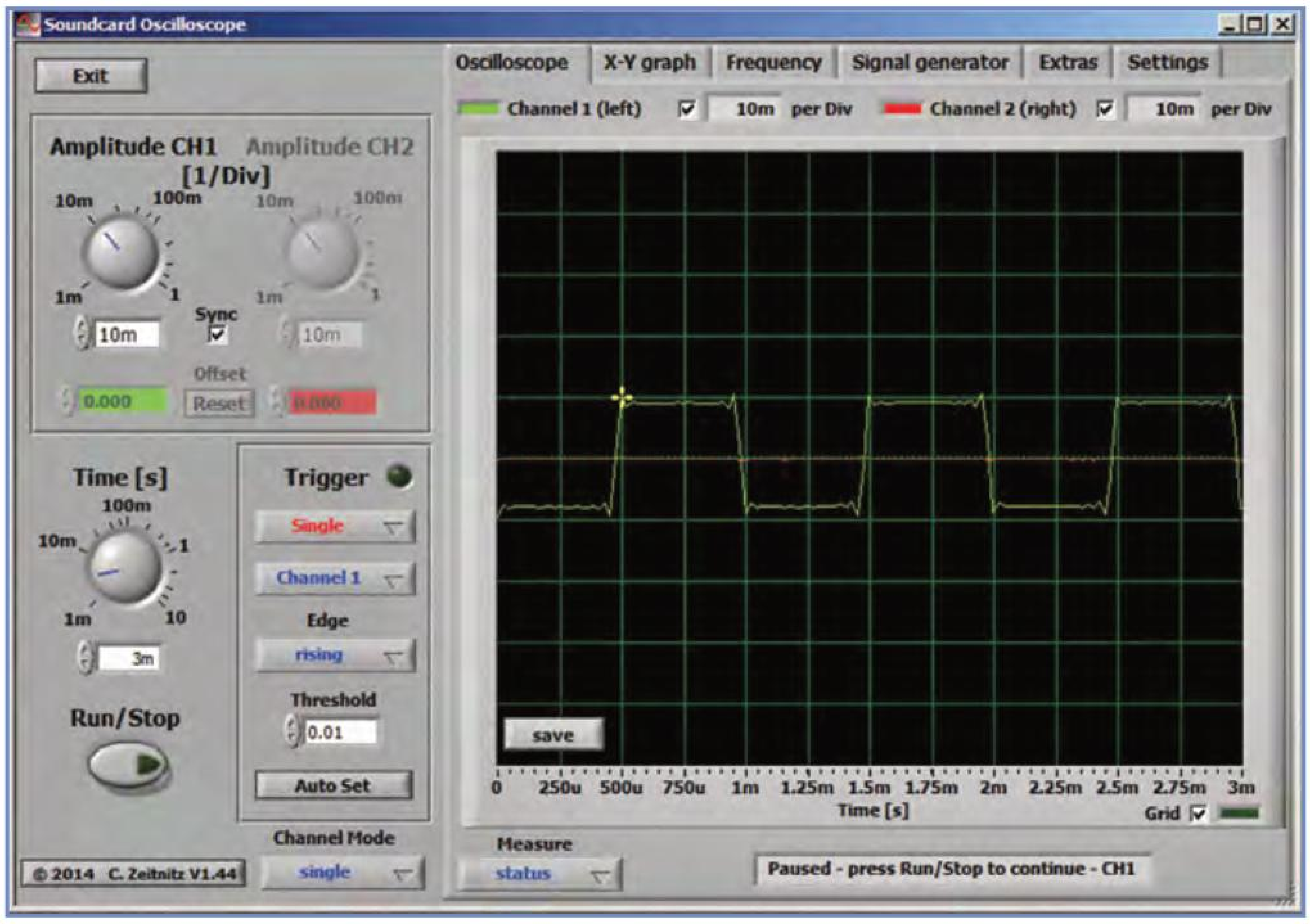


Fig.2.23. Output of the scope calibrator displayed using the Soundcard Oscilloscope (note that the rise and fall times have both been significantly increased due to the soundcard's limited high frequency response)

Setting up

No setting up is required after assembly – all you need to do is to connect a PP3 battery and switch on! D1 should become illuminated; if not, check the battery and circuit connections carefully.

Next, connect the output (SK1) via a short coaxial jump lead fitted with two BNC male connectors to the Y1 (Channel A) input of your oscilloscope. Set the timebase to 500µs/cm and the Y-attenuator to 2V/cm. The scope should display a square wave with an amplitude of 5V (2.5cm vertical deflection) and a period of 1ms (2cm for one complete cycle).

Next month

In next month's *Teach-In 2018* we will be looking at AC measurements and our practical project will feature a wide-band RMS voltage adapter that can be used to improve the AC performance of most digital multimeters.

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Farnell H60/50	PSU 0-60V 0-50A	£500
Farnell XA35/2T	PSU 0-35V 0-2A Twice Digital	£75
Farnell LF1	Sine/sq Oscillator 10HZ-1MHZ	£45
Racal 1991	Counter/Timer 160MHZ 9 Digit	£150
Racal 2101	Counter 20GHZ LED	£295
Racal 9300	True RMS Millivoltmeter 5HZ-20MHZ etc	£45
Racal 9300B	As 9300	£75
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Fluke 99B	Scopemeter 2 Channel 100MHZ 5GS/S	£125
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Seaward Nova	PAT Tester	£95
Solartron 7150/PLUS	6 1/2 Digit DMM True RMS IEEE	£65/£75
Solatron 1253	Gain Phase Analyser 1mHZ-20KHZ	£600
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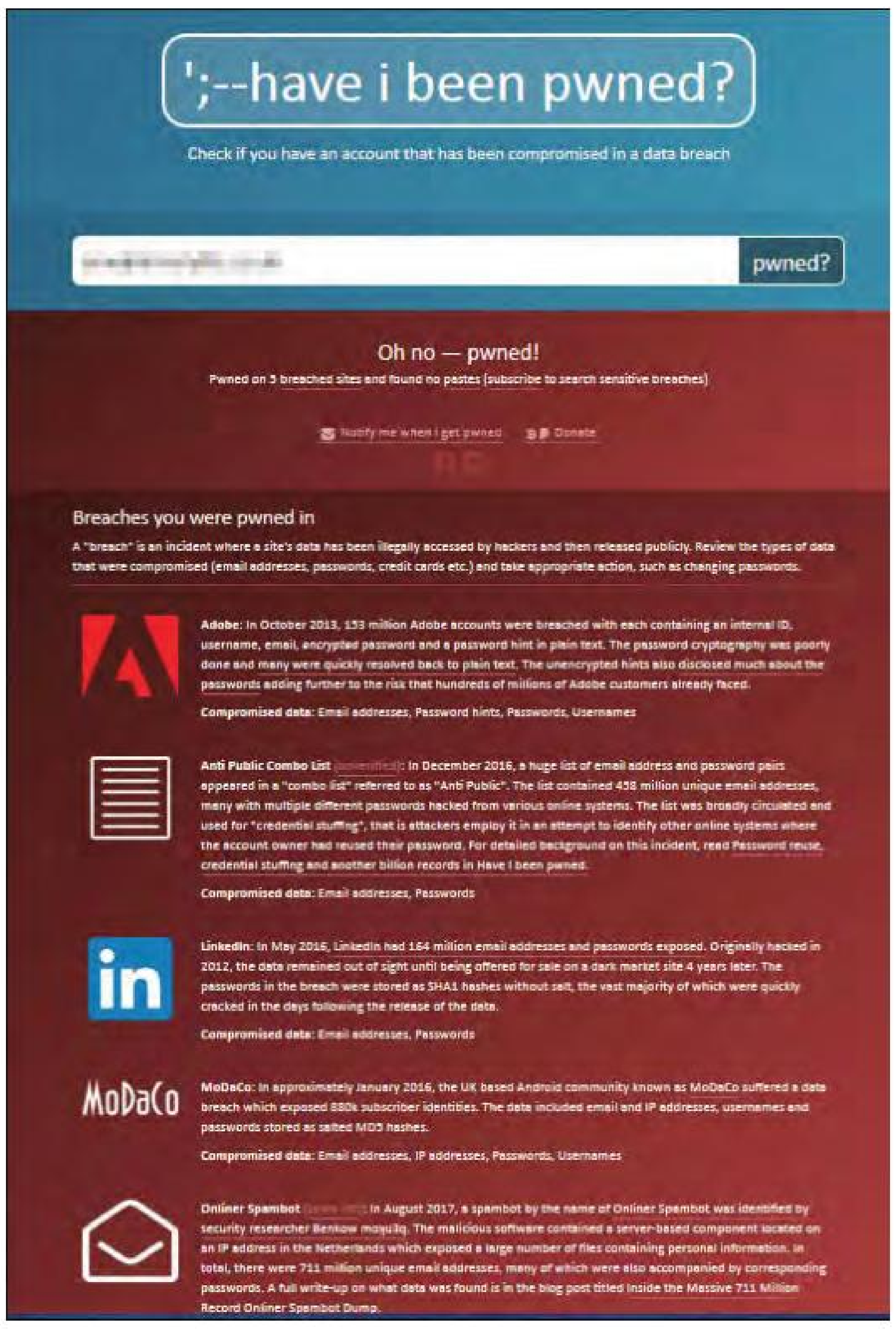
NET WORK

by Alan Winstanley

Flakey apps

INTERNET ACCESS is now taken virtually for granted by users at home, at work and on holiday. Owners of smartphones and tablets have an armoury of apps at their disposal that are just a click away, downloadable from Apple or Google Play Store. Microsoft too decided that downloadable apps was the way ahead and Windows from version 8.1 onwards refers to 'apps' rather than programs. The quality and risk posed by some apps is questionable, though, especially in the Internet 'wild west' that is dominated by Android. In mid-August Google pulled the plug on some 300 Android apps that were implicated in a botnet that was hosted by tens of thousands of Android devices and was responsible for DDoS attacks.

In the same month, both Apple and Google deleted another 300-odd financial trading apps from their stores as they exposed users to extreme financial risks or they were simply harvesting personal details that could potentially be used to perpetrate boiler-room type scams. More apps have also been guillotined by Google recently: a further 500 of them were pulled as they potentially hosted spyware that could steal private data. Mobile games played by teens and weather apps were included in the crop of dodgy apps silently spirited away on the Google Play Store.



Check if you have an account that has been compromised in a data breach

[redacted]

Oh no — pwned!

Pwned on 5 breached sites and found no pastes (subscribe to search sensitive breaches)

Breaches you were pwned in

A "breach" is an incident where a site's data has been illegally accessed by hackers and then released publicly. Review the types of data that were compromised (email addresses, passwords, credit cards etc.) and take appropriate action, such as changing passwords.

Adobe: In October 2013, 153 million Adobe accounts were breached with each containing an internal ID, username, email, encrypted password and a password hint in plain text. The password cryptography was poorly done and many were quickly resolved back to plain text. The unencrypted hints also disclosed much about the passwords adding further to the risk that hundreds of millions of Adobe customers already faced.

Compromised data: Email addresses, Password hints, Passwords, Usernames

Anti Public Combo List (unverified): In December 2016, a huge list of email address and password pairs appeared in a "combo list" referred to as "Anti Public". The list contained 458 million unique email addresses, many with multiple different passwords hacked from various online systems. The list was broadly circulated and used for "credential stuffing", that is attackers employ it in an attempt to identify other online systems where the account owner had reused their password. For detailed background on this incident, read Password reuse, credential stuffing and another billion records in Have I been pwned.

Compromised data: Email addresses, Passwords

LinkedIn: In May 2016, LinkedIn had 164 million email addresses and passwords exposed. Originally hacked in 2012, the data remained out of sight until being offered for sale on a dark market site 4 years later. The passwords in the breach were stored as SHA1 hashes without salt, the vast majority of which were quickly cracked in the days following the release of the data.

Compromised data: Email addresses, Passwords

MoDaCo: In approximately January 2016, the UK based Android community known as MoDaCo suffered a data breach which exposed 880k subscriber identities. The data included email and IP addresses, usernames and passwords stored as salted MD5 hashes.

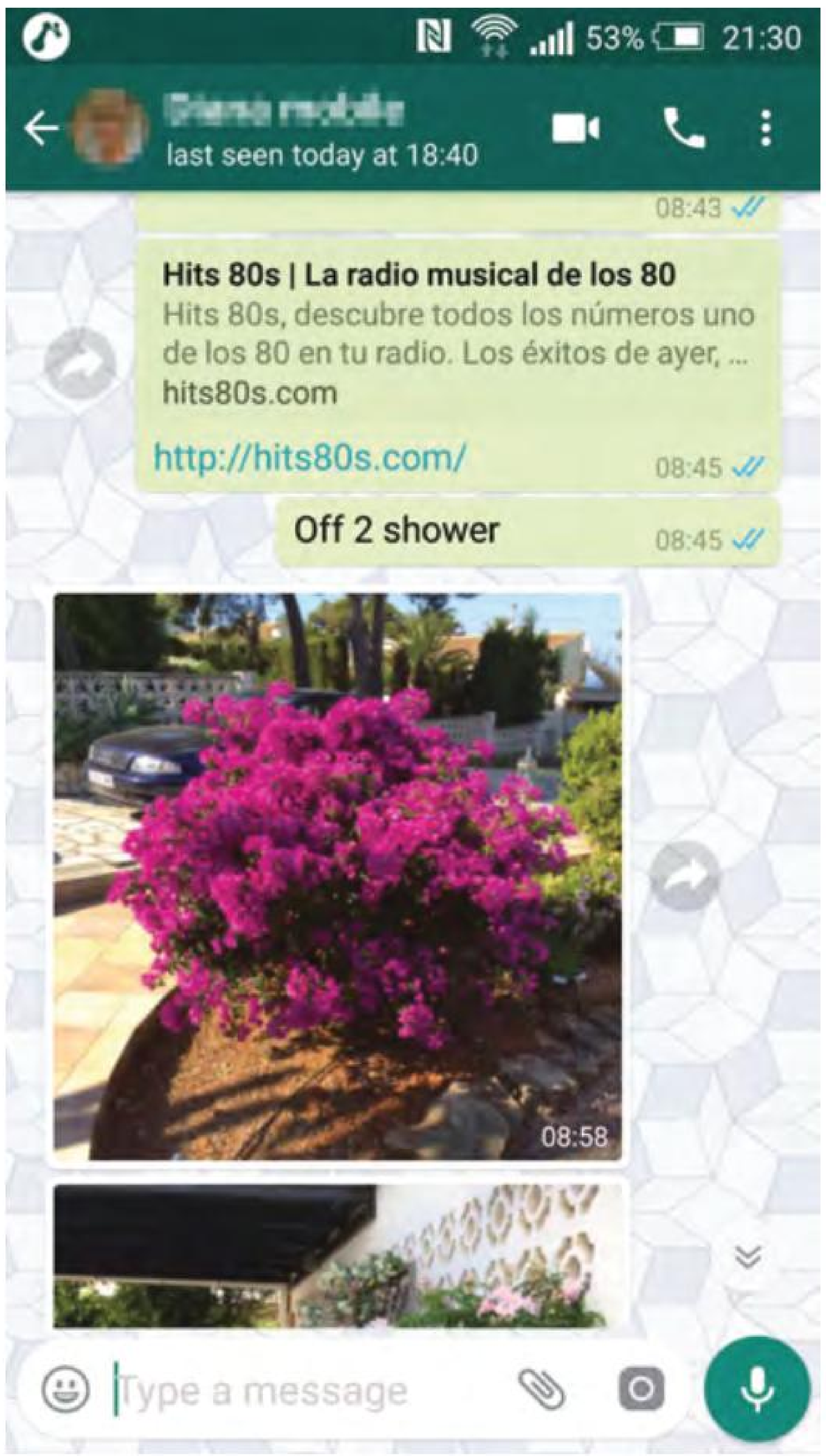
Compromised data: Email addresses, IP addresses, Passwords, Usernames

Onliner Spambot (spam list): In August 2017, a spambot by the name of Onliner Spambot was identified by security researcher Benkow moquilq. The malicious software contained a server-based component located on an IP address in the Netherlands which exposed a large number of files containing personal information. In total, there were 711 million unique email addresses, many of which were also accompanied by corresponding passwords. A full write-up on what data was found is in the blog post titled Inside the Massive 711 Million Record Onliner Spambot Dump.

The Have I Been Pwned? website indicates whether your email address is contained in the latest dump of 0.7 billion addresses: if it has been, it's best to change logins again

As if flakey apps aren't enough to worry about, in the same month more than 0.7 *billion* email addresses and passwords were leaked onto the web, a bonanza that would help spammers to transmit yet more of their unsolicited junk. An insightful analysis of this latest spambot dump (14GB+ of it) has been posted by Troy Hunt at **https://www.troyhunt.com/inside-the-massive-711-million-record-onliner-spambot-dump/** .

Although it does not follow that your email passwords were also stolen, it's probably wise to change them anyway, which can be a nuisance when you use multiple email clients or devices for checking your mailbox. Troy Hunt also fed the massive database into the website Have I Been Pwned?, see **https://haveibeenpwned.com** where you can check whether your address has been implicated in the data loss. The screenshot shows how one of my own regular addresses has indeed fallen prey to this data theft, so I'm off to change my logins right away!



[redacted]
last seen today at 18:40

Hits 80s | La radio musical de los 80
Hits 80s, descubre todos los números uno de los 80 en tu radio. Los éxitos de ayer, ...
hits80s.com
http://hits80s.com/ 08:45

Off 2 shower 08:45

Whatsapp is the king of mobile messenger apps, offering chat, photo and link sharing, voice and video calling. A holiday chat session while abroad, shown here

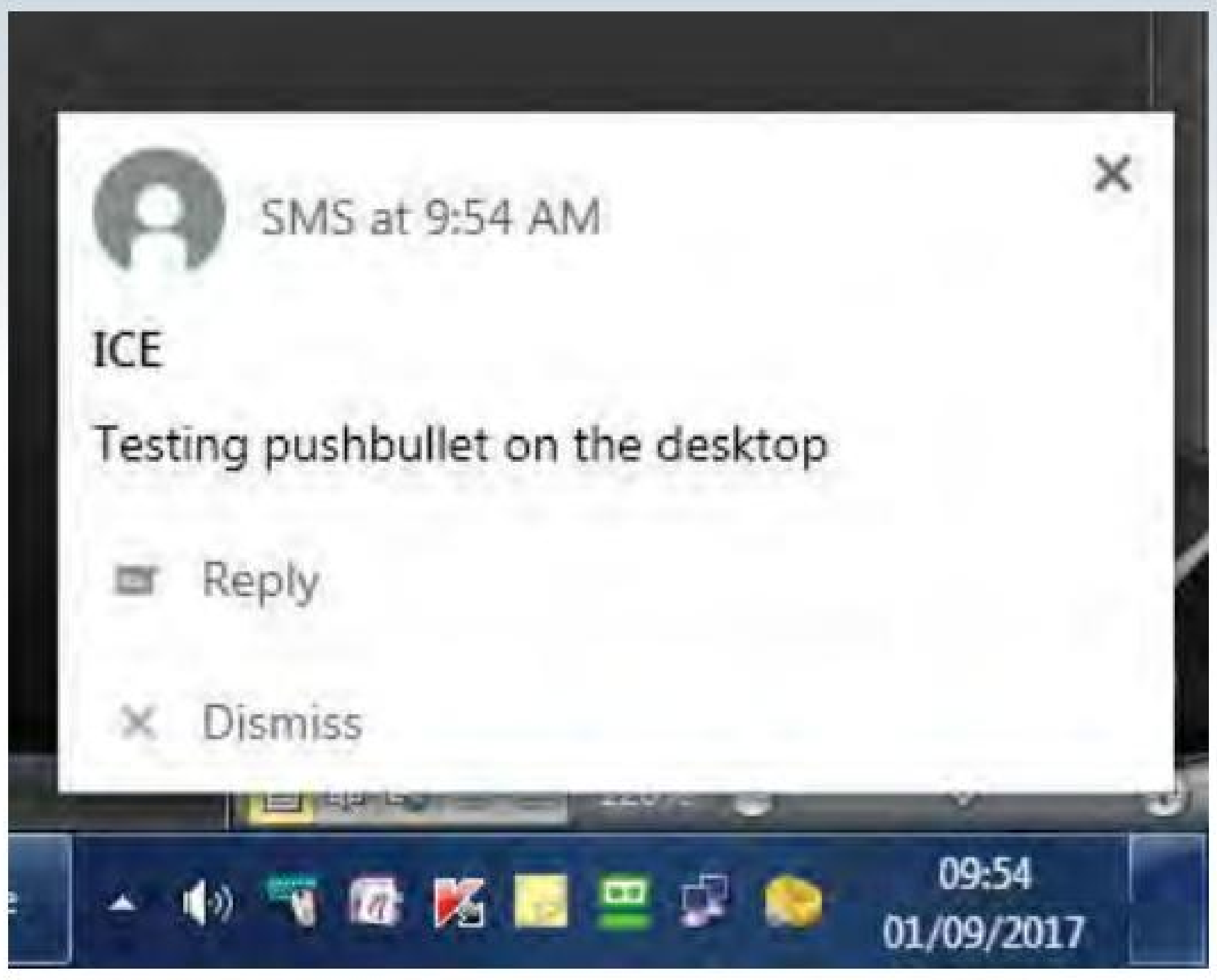
Whatsapp, Doc?

Despite the questionable inconsistency in the trust and quality of downloadable apps, there are plenty of useful ones including some that I could not live without. One of the most useful mobile apps available has to be Whatsapp, a service used by a claimed 1 billion people in over 180 countries. For many users, Whatsapp is the king of messenger apps: genuinely useful, and a great money saver especially when travelling overseas or keeping up with contacts. The classic messenger interface makes it easy to chat terminal-style with others, and it's more rewarding and intuitive to use than SMS messaging. You can send photos, attach documents and send location info as well. For a bit of fun, the usual crop of emoticons can lighten conversations.

Brief audio clips can be recorded using the microphone and sent through Whatsapp the same way, and thanks to Android's voice recognition system, it is extremely easy to dictate messages instead of laboriously typing them. Android generally does a very good job of translating speech into text and, for the writer anyway, speaking and converting to text this way is now the preferred way of 'typing' messages to someone using Whatsapp. (Yes I know – I suppose you could just phone them up!) It is rapid and rewarding to use, and groups of up to 256 Whatsapp users can be set up to broadcast to them all simultaneously. Against each message a tick mark will be seen: a single grey tick indicates message sent, two ticks for message received and two blue ticks mean the message has been seen by the recipient (see screenshot).

There's more to Whatsapp: provided that both users are hooked up to some reasonable Wi-Fi bandwidth, it is easy to place an IP phonecall and you can soon be talking with each other in real time. Of course, data usage can cost money, but if Internet access is free or bundled (eg via a secure Wi-Fi hotspot or router in a holiday villa or hotel, say), talking this way is effectively free and your mobile phone's data tariffs can be left untouched. Occasionally there may be the odd line-drop or break up, but it is still possible to hold lengthy phone conversations successfully. And if you want to go the extra mile, Whatsapp makes it easy to make a video call, Skype-style, though some juddering and lag are sometimes to be expected dependent on available bandwidth. Many an enriching video call has been made with other Whataspp users halfway round the world, and in the author's book this makes Whatsapp top of the list of must-have apps.

You can download Whataspp for your platform by pointing your device's browser to **https://whatsapp.com/dl** and versions for Android, iPhone, Windows, Nokia S40 and Blackberry are available. Having installed the mobile version, you can then fetch desktop apps as well. Give it a go!


SMS at 9:54 AM

ICE

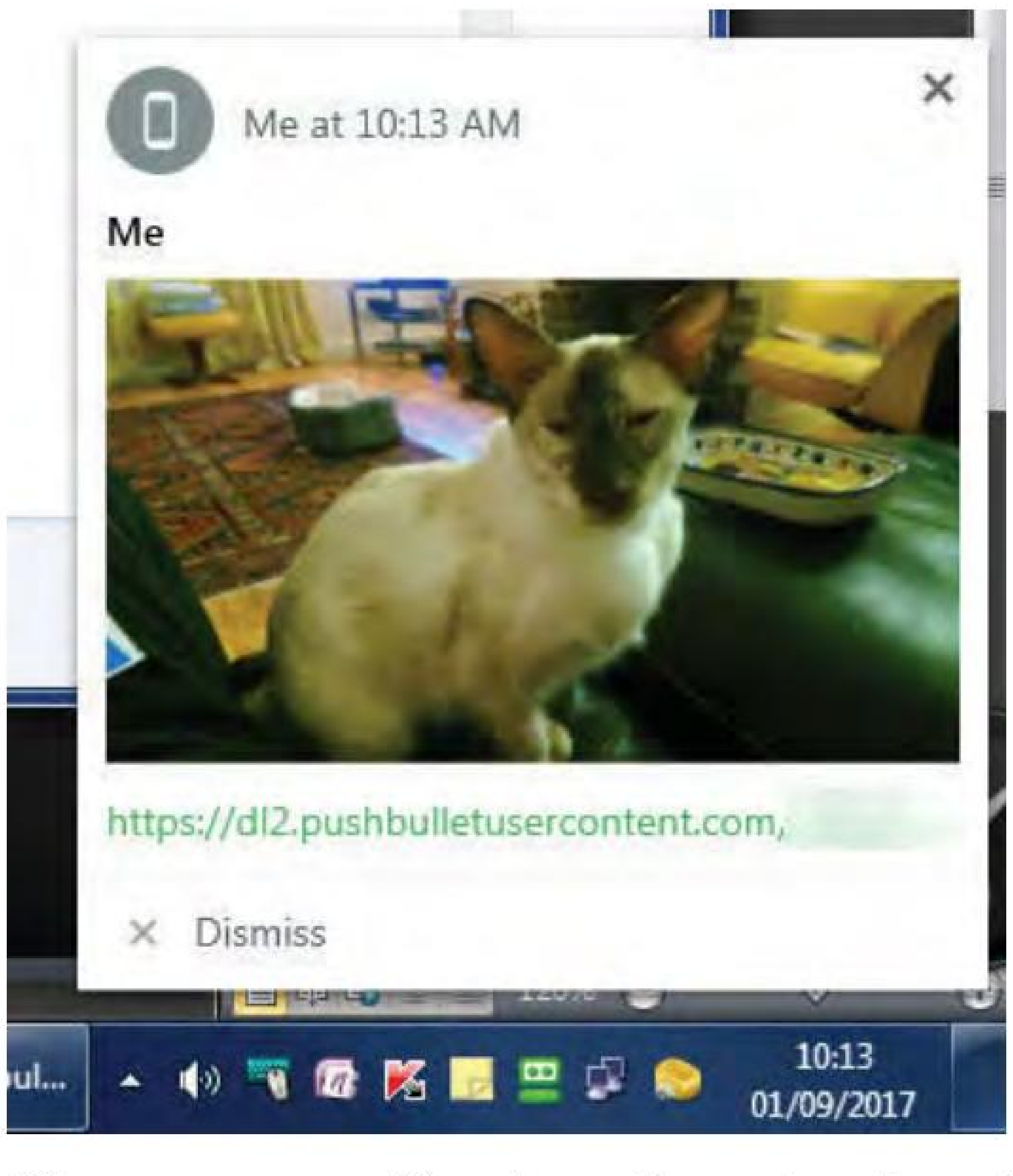
Testing pushbullet on the desktop

Pushbullet can send SMS popups to your desktop, and handle replies too

Take aim with Pushbullet

Next on the author's list of useful network utilities is **Pushbullet,** a simple but handy app that lets you 'fire' content at any other device hosted on your network. For example, you might capture a screenshot on your tablet or grab a hyperlink that you want to copy to another machine on your LAN. There are various ways of doing so, but Pushbullet makes the job of sharing content easy: just 'aim' at your target device and the file or hyperlink is transferred fuss-free via the cloud with a single click. Pushbullet then makes importing the content a cinch – today, for example, I had to email a photo of a shower electric pump to its manufacturer. Many would use a cloud email service on a mobile phone, but if you need to transfer the image to a PC or laptop instead, it is simple to take a photo with a mobile phone and then use Pushbullet to share it with a PC. After downloading the image from the cloud it can be embedded in my main email correspondence that way.

Pushbullet is a deceptively powerful app and worth getting to grips with. Just as Whataspp can replace SMS, if you are still wedded to SMS texting then Pushbullet will let you send SMS messages from your desktop. Very usefully, the app can display your mobile phone's notifications on your desktop too – so Whatapp and SMS pop-ups appear on my PC and can be replied to that way, which for many users might be its best feature. You can also message your friends.


Me at 10:13 AM

Me

https://dl2.pushbulletusercontent.com/

Glamourpuss: Coco's selfie gets shared with Pushbullet – a PC desktop popup (shown) contains the download link

The free version of Pushbullet allows 25MB file size and 2GB of cloud storage of your files, and up to 100 SMS messages per month. A paid-for Pro version lifts these limits to 1GB/ 100GB and unlimited, respectively. You can download Pushbullet for iPhone and Android in the usual way.

Last, this month, a reminder that the old *EPE Chat Zone* is being semi-retired from October, but readers can be assured we are working behind the scenes to relocate our online forum to a new home. The old forum will be preserved in 'read-only' noticeboard mode for the foreseeable future and *EPE* will still post news and updates there, so be sure to check for latest news. We hope to have more news for *EPE Chat Zone* users in coming weeks.

You can contact the author at **alan@epemag.net**

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PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

Microchip's Plugins and the Code Configurator

IN LAST MONTH'S PIC project we built a very simple sinewave generator using a handful of components and some firmware involving look up tables. This month, I want to take a look at some of the extra features in the MPLAB X IDE that will make setting up future projects a little easier.

MPLAB X plugins

MPLAB X is an all-in-one integrated development environment, or IDE. Typically, this is used for developing code and programming it to the chosen PIC microcontroller using a PICkit, ICD or ICE external programmer. It is also used for debugging problems in the code and verifying the code's behaviour.

MPLAB X also provides the possibility of adding a number of plugins that can improve upon the features and functionality of the IDE. There are roughly 50 basic plugins automatically installed with the IDE initially. These include repository tools for backing up your code like Git, Mercurial and Subversion. Bugzilla is another tool that can be used for bug tracking. For working on larger pieces of code, bug tracking can be extremely useful and far better than the standard spreadsheet approach. There's even an in-built spellchecker for various languages.

Extra plugins can be downloaded automatically through the Plugins window. This window can be accessed by selecting the Tools menu in MPLAB X IDE, and then selecting the Plugins option. This will open the Plugins window, where we can see available updates for the installed plugins, available plugins that can be added, downloaded plugins, installed plugins and settings.

One of the most useful plugins is Microchip's Code Configurator. It is a GUI (graphical user interface) that works alongside MPLAB to help users setup GPIOs, clocks, modules and much more. While it is nice being able to do it manually, and we have covered it thoroughly in the *PIC Beginner's Guide*, it's even nicer to take away some of the more tedious tasks, allowing us to focus on functionality. It does sound quite basic, but as we take a deeper look inside the plugins, we will find there's a lot more to them than first meets the eye.

Other available plugins

There are a number of useful tools available to be downloaded. Some of the plugins need the use of the REAL ICE programmer, which is a little more expensive, but can make a serious difference in development time for larger embedded projects. Sticking with the plugins that can work with the PICkit 3, there are a few good plugins that can be very useful.

Data Monitor and Control Interface (DCMI) offers the developer the ability to interact with the application while it is running via a GUI. This helps reduce debugging time for more complicated embedded applications.

MemoryStarterKit allows the developer to program and verify the contents of a Microchip serial EEPROM. The EEPROM can work over I^{2}C, SPI, microwire or UNI/O bus protocols. It is a great debug tool for anyone using an external EEPROM in their design.

PCLint is a Gimpel PC-lint/MISRA plugin, which can perform standard checks on C source files created in MPLAB X. It can be used to find bugs, glitches, inconsistencies, non-portable constructs, redundant code and much more. It can be customised to give you a lot of small errors or only tell you about larger errors.

VGDD-Link enables the use of the VGDD wizard (Visual Graphics Display Designer), which is an IDE that can be called from within MPLAB X to develop complex user interfaces based on Microchip's GOL (Graphics Object Library). The PIC24 and PIC32 support the GOL widgets. This Designer can also be used to convert pictures and fonts so they can be used in a project. It works directly with MPLAB X to automatically generate the necessary code to develop a GUI. Note that VGDD-Link is only a plugin to enable the use of the VGDD wizard, which is *not* a free third-party plugin.

Code Profiler enhances the debugging capability of MPLAB X, using the MPLAB REAL ICE (In-Circuit Emulator) to measure the percentage of time spent in each function. This allows you to figure out where the application may be spending most of its time and thus it helps in optimising code. Note that this is only a trial version – the full version can be purchased on Microchip's website.

Remote USB Debugging is a handy plugin that allows the developer to use debug tools from a remote location. It's an alternative to VNC and all that is needed is the MPLAB Communications library and the JRE from the MPLAB X IDE v3.40 or later. This means you could remotely debug a system from a Raspberry Pi.

Halt Notifier can be used to alert when a target PIC microcontroller has been halted. These alerts can be customised with actions such as audio alert, send an email or run a script.

Power Monitor is used with the REAL ICE programmer to monitor real-time power usage of user programs. This is a really interesting plugin, but the need for the REAL ICE programmer places it outside the ability of the average developer, which is a pity.

There are over 200 third-party plugins that can be used with MPLAB X. These are available on Microchip's website: **www.microchip.com/devtoolthirdparty**

They include tools such as Mikroelectronika's Visual TFT and mikroC, which provide a large library of functions to rapidly design products with ease.

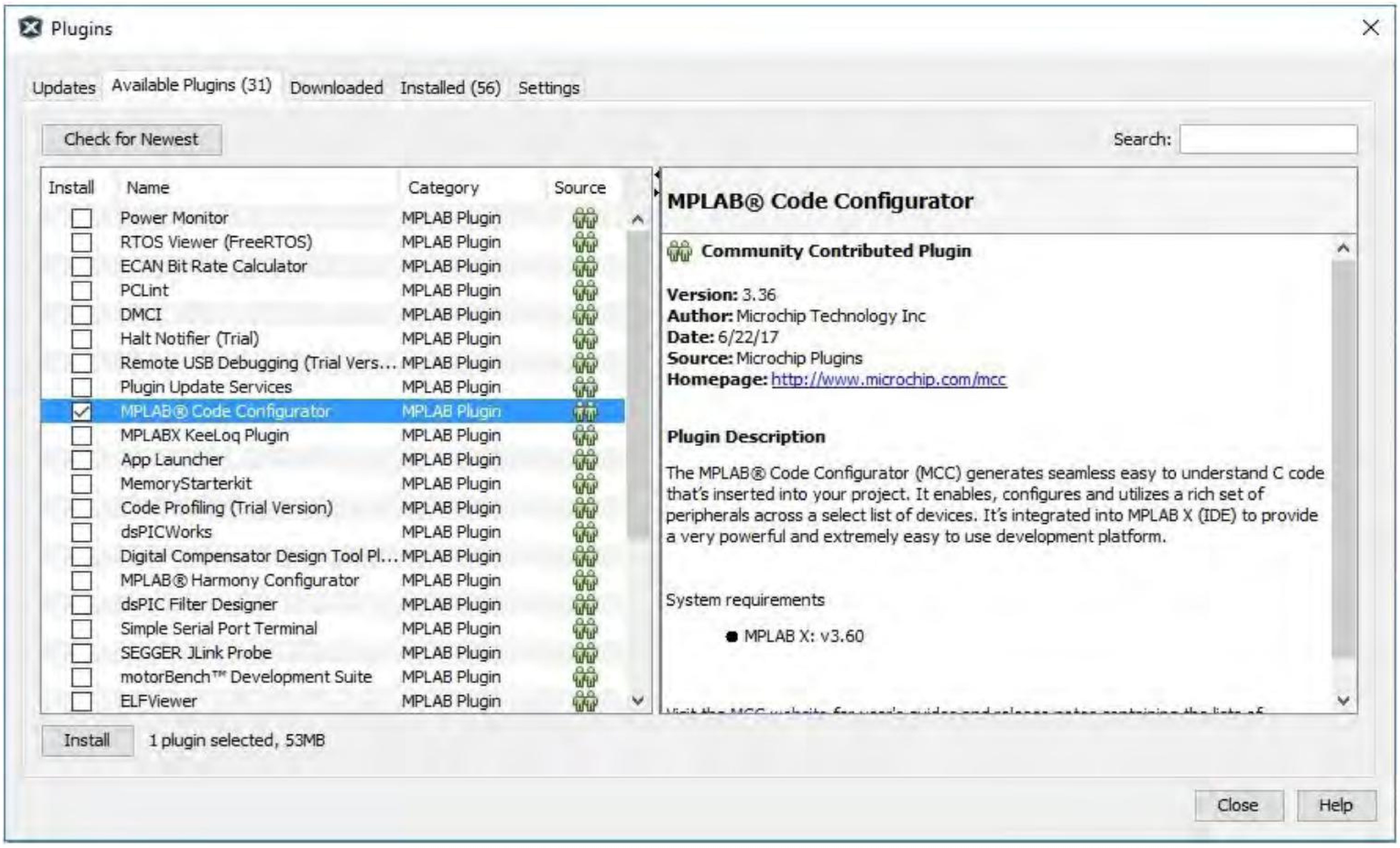
Getting started with the Code Configurator

Getting back to the Code Configurator, it can be installed in three ways: through the online MPLAB Xpress cloud-based IDE; installation of the plugin in the MPLAB X IDE; or you can manually install the plugin by downloading the installation file.

I'll cover the MPLAB Xpress cloud-based IDE some other time. It is an interesting version of MPLAB X, as an alternative to downloading the entire IDE to your personal PC or laptop.

The easiest way to install the plugin is to install it through MPLAB X. In order to install the Code Configurator, MPLAB X version 3.60 or later is needed. At the time of writing, the current version of MPLAB X is v4.0. Once that has been updated, open the Tools menu along the menu bar and select Plugins. This will open a new window, as seen in Fig.1. We can also see some of the other plugins we mentioned earlier in this window.

Once the Code Configurator has been installed, it can be accessed


Plugins
Updates
Available Plugins (31)
Downloaded
Installed (56)
Settings
Check for Newest
Search:
Install
Close
Help

Install	Name	Category
☐	Power Monitor	MPLAB Plugin
☐	RTOS Viewer (FreeRTOS)	MPLAB Plugin
☐	ECAN Bit Rate Calculator	MPLAB Plugin
☐	PCLint	MPLAB Plugin
☐	DMCI	MPLAB Plugin
☐	Halt Notifier (Trial)	MPLAB Plugin
☐	Remote USB Debugging (Trial Vers…	MPLAB Plugin
☐	Plugin Update Services	MPLAB Plugin
☑	MPLAB® Code Configurator	MPLAB Plugin
☐	MPLABX KeeLoq Plugin	MPLAB Plugin
☐	App Launcher	MPLAB Plugin
☐	MemoryStarterkit	MPLAB Plugin
☐	Code Profiling (Trial Version)	MPLAB Plugin
☐	dsPICWorks	MPLAB Plugin
☐	Digital Compensator Design Tool Pl…	MPLAB Plugin
☐	MPLAB® Harmony Configurator	MPLAB Plugin
☐	dsPIC Filter Designer	MPLAB Plugin
☐	Simple Serial Port Terminal	MPLAB Plugin
☐	SEGGER JLink Probe	MPLAB Plugin
☐	motorBench™ Development Suite	MPLAB Plugin
☐	ELFViewer	MPLAB Plugin

1 plugin selected, 53MB

MPLAB® Code Configurator

Community Contributed Plugin

Version: 3.36
Author: Microchip Technology Inc
Date: 6/22/17
Source: Microchip Plugins
Homepage: http://www.microchip.com/mcc

Plugin Description

The MPLAB® Code Configurator (MCC) generates seamless easy to understand C code that's inserted into your project. It enables, configures and utilizes a rich set of peripherals across a select list of devices. It's integrated into MPLAB X (IDE) to provide a very powerful and extremely easy to use development platform.

System requirements

- MPLAB X: v3.60

Fig.1. MPLAB X Plugins Window

from either the toolbar under Tools and Embedded, or you can click on the MCC icon highlighted in green in Fig.2.

Setting up a GPIO

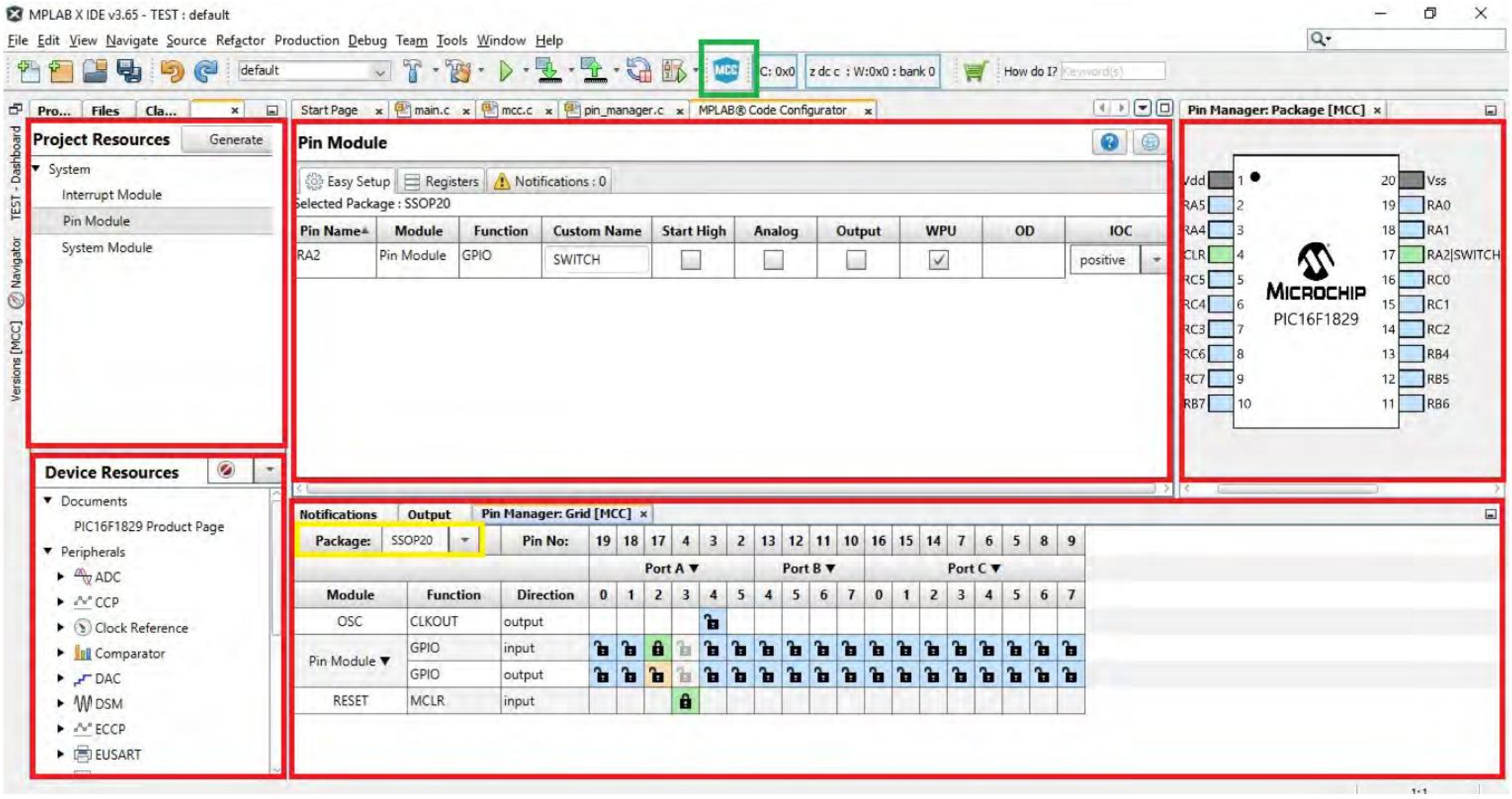
In order to demonstrate a few examples of the Code Configurator's operation, we will take last month's schematic to work from, as shown in Fig.3. We're going to add the switch functionality on Port A2 using the Code Configurator. Normally, using the Code Configurator for just one pin would be seen as a bit excessive, but it will suffice for demonstration purposes.

When setting up a GPIO on a device, we're interested in three things: setting up the direction of the pin as either an input or output, setting the pin up as digital or analogue and finally, if it's an output, we need to select whether we latch it high or low. Typically in code, this would look like the following:

```
LATAbits.RA2 = 0;
TRISAbits.TRISA2 = 0;
ANSELAbits.ANSA2 = 0;
```

This takes the port A2 and sets it as a digital output low. If we have only a few GPIOs to setup, then this is trivial. However, as our designs grow and become more complicated it can be a chore finding out how each port is connected and manually writing up each one.

Now take a look at setting up the pin through the Code Configurator. See Fig.2 for a screenshot of the Code Configurator inside MPLAB X. Top left, there is Project Resources, where we select which part of the system we


MPLAB X IDE v3.65 - TEST : default
File Edit View Navigate Source Refactor Production Debug Team Tools Window Help
default
MCC
How do I?
Start Page
main.c
mcc.c
pin_manager.c
MPLAB® Code Configurator
Pin Manager: Package [MCC]
Project Resources
Generate
System
Interrupt Module
Pin Module
System Module
Device Resources
Documents
PIC16F1829 Product Page
Peripherals
ADC
CCP
Clock Reference
Comparator
DAC
DSM
ECCP
EUSART
Pin Module
Easy Setup
Registers
Notifications : 0
Selected Package : SSOP20
Vdd
RA5
RA4
CLR
RC5
RC4
RC3
RC6
RC7
RB7
Vss
RA0
RA1
RA2|SWITCH
RC0
RC1
RC2
RB4
RB5
RB6
MICROCHIP
PIC16F1829
Notifications
Output
Pin Manager: Grid [MCC]

Pin Name	Module	Function	Custom Name	Start High	Analog	Output	WPU	OD	IOC
RA2	Pin Module	GPIO	SWITCH	☐	☐	☐	☑		positive

Package: SSOP20

		Pin No:	19	18	17	4	3	2	13	12	11	10	16	15	14	7	6	5	8	9
			Port A ▼						Port B ▼				Port C ▼							
Module	Function	Direction	0	1	2	3	4	5	4	5	6	7	0	1	2	3	4	5	6	7
OSC	CLKOUT	output					🔓													
Pin Module ▼	GPIO	input	🔓	🔓	🔒	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓
	GPIO	output	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓	🔓
RESET	MCLR	input				🔒														

Fig.2. Microchip's Code Configurator window layout

want to edit. Below that are the Device resources, where designers select which module is added to the system. In the centre is the resources window based on the selection made in Project Resources. Fig.2 shows the Pin Module is selected. In the top right is an image of the IC package for the PIC16F1829. Down the bottom is the Pin Manager. Note that to change the selected package in the package window, use the drop down menu in the Pin Manager highlighted in yellow in Fig.2.

In the Pin Manager, simply click on the blue unlocked box under Port A, pin 2 for a GPIO output. As seen in Fig.2, once this is selected, it turns green and is now shown in the Pin Module window above. In the Pin Module window, we can give the pin a custom name, instead of ‘IO_RA2’, let’s call it ‘SWITCH’. This will be highlighted in the IC Package window. This variable name SWITCH will now be used throughout the code to refer to the input state of Port A2.

There are a few other options here. Start High ensures that the pin is held high after a reset. This is a useful feature in control circuits. De-select the Analog option as this will be a digital output. The Output option should be selected as well. WPU indicates this pin has an optional internal pull-up, which reduces component count. Leave this enabled because it is connected to a switch and needs the pull-up. OD refers to ‘open drain’ and there is no click box here, indicating it is not available for this pin. The last option is IOC, which is Interrupt on Change. This can be changed to interrupt on any change on the pin, negative change (falling edge) or positive change (rising edge). As this is connected to a momentary button that pulls the output low when pressed, we should use this IOC option to try and capture the button press. In this situation, we can choose either negative or positive change to capture a button press. Using the ‘any change’ option could capture both negative and positive changes and trigger the interrupt twice as a result. This is why it’s better to capture either the negative or the positive, but not both. There are other situations where the ‘any’ option would work.

Finally, click on the Generate button in the Project Resources window. This will generate the necessary code. A number of files will be created, with a variety of functions that can now be easily used throughout the code.

Code 1:

```
#include <xc.h>
#include “pin_manager.h”
#include “stdbool.h”

void PIN_MANAGER_Initialize(void){
    LATA = 0x00;
    LATB = 0x00;
    LATC = 0x00;

    TRISA = 0x3F;
    TRISB = 0xF0;
    TRISC = 0xFF;

    ANSELC = 0xCF;
    ANSELB = 0x30;
    ANSELA = 0x17;

    WPUB = 0xF0;
    WPUA = 0x3F;
    WPUC = 0xFF;
    OPTION_REGbits.nWPUEN = 0;

    APFCON1 = 0x00;
    APFCON0 = 0x00;

    IOCAFbits.IOCAF2 = 0;
    IOCANbits.IOCAN2 = 0;
    IOCAPbits.IOCAP2 = 1;
    IOCAF2_
SetInterruptHandler(IOCAF2_
DefaultInterruptHandler);
}
```

The generated code

Taking a look at the generated code, we can see there’s a lot more code generated than the three lines we wrote earlier to set up the one GPIO. Through the choices we’ve made, we’ve also set this one pin as a digital input, with an internal pull-up and also enabled the Interrupt on Change interrupt (see **Code 1**).

The Code Configurator has not just setup the one pin as we were expecting, but it has individually set up each and every pin with a default setting. This is actually good practice because it ensures that each pin is specifically defined at start up. Instead of placing all of the definitions in the main `while` loop, it has created a separate C file called `pin_manager.c` which contains all the functions created by the MCC. The specific function `PIN_MANAGER_Initialize` is called in the main `while` loop at the start of code execution to define each of the pins.

Taking a look at the code above, we can see that every pin on Port A, B and C is set to output low using the LAT definition. Next, the TRIS registers are all set as inputs. The analogue select registers (ANSELx) are then used to set all the pins as digital pins (where 0 is for analogue and 1 for digital). The weak pull-up registers (WPUx) set all the pins to enable weak pull-ups, but the global `OPTION_REGbits.nWPUEN` is set to 0, meaning weak pulls-up are disabled.

The next group of registers to be set is the Alternate Pin Function control registers (APFCON), which can be used to steer specific peripherals between different pins. These are all set to 0, meaning there is no function swapping between pins.

The last group of registers set up the Interrupt on Change pins to interrupt on a rising edge and to use the `DefaultInterruptHandler`. We will see what this is in the next piece of code.

```
void PIN_MANAGER_IOC(void){
    if(IOCAFbits.IOCAF2 == 1){
        IOCAF2_ISR();
    }
}

void IOCAF2_ISR(void) {
    if(IOCAF2_InterruptHandler){
        IOCAF2_InterruptHandler();
    }
    IOCAFbits.IOCAF2 = 0;
}

void IOCAF2_SetInterruptHandler(void*
InterruptHandler){
    IOCAF2_InterruptHandler = InterruptHandler;
}

void IOCAF2_DefaultInterruptHandler(void){
}
```

If we take a look at the rest of the contents inside the `pin_manager.c` file, we can see the rest of the code above has been inserted. This piece of code sets up and organises the interrupt service routine for the Interrupt on Change pin. As we saw earlier in the code, `DefaultInterruptHandler` was chosen as the default handler. If we look at the function here, we notice it is empty, therefore nothing will happen when a change is seen. This is where we would place new code to be performed upon a change notification.

This really only gives us a glimpse into what the Code Configurator can do. Once all the pins have been selected in the GUI interface, we can generate the code that will be inserted into the project. There’s also another file created called `mcc.c`, which handles the `SYSTEM_Initialize`, `OSCILLATOR_Initialize` and `WDT_Initialize` function calls, which are used to set up the system. Then, in the `main.c` file, we can see that the MCC header file is included at the top of the code:

```
#include “mcc_generated_files/mcc.h”
```

Note also that the `SYSTEM_Initialize` function is called, which in turn calls all of the other functions before returning to the main `while` loop.

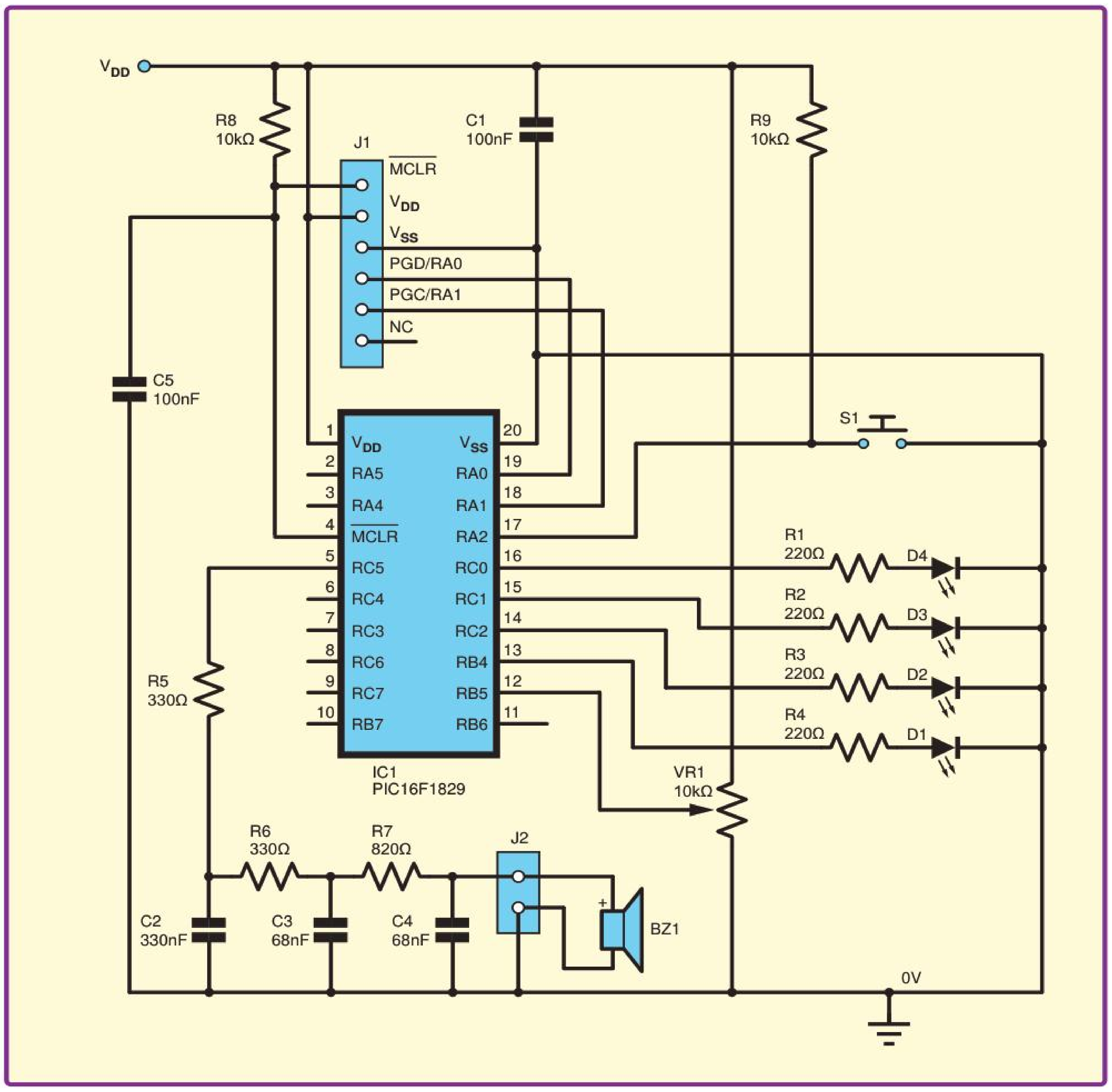
The plugin is incredibly powerful and really shows its strength when setting up modules like the ADC, UART, PWM and DAC.

The test project created for this demonstration can be downloaded from the *EPE* website. This will help you follow along and see what changes have been made.

Next month

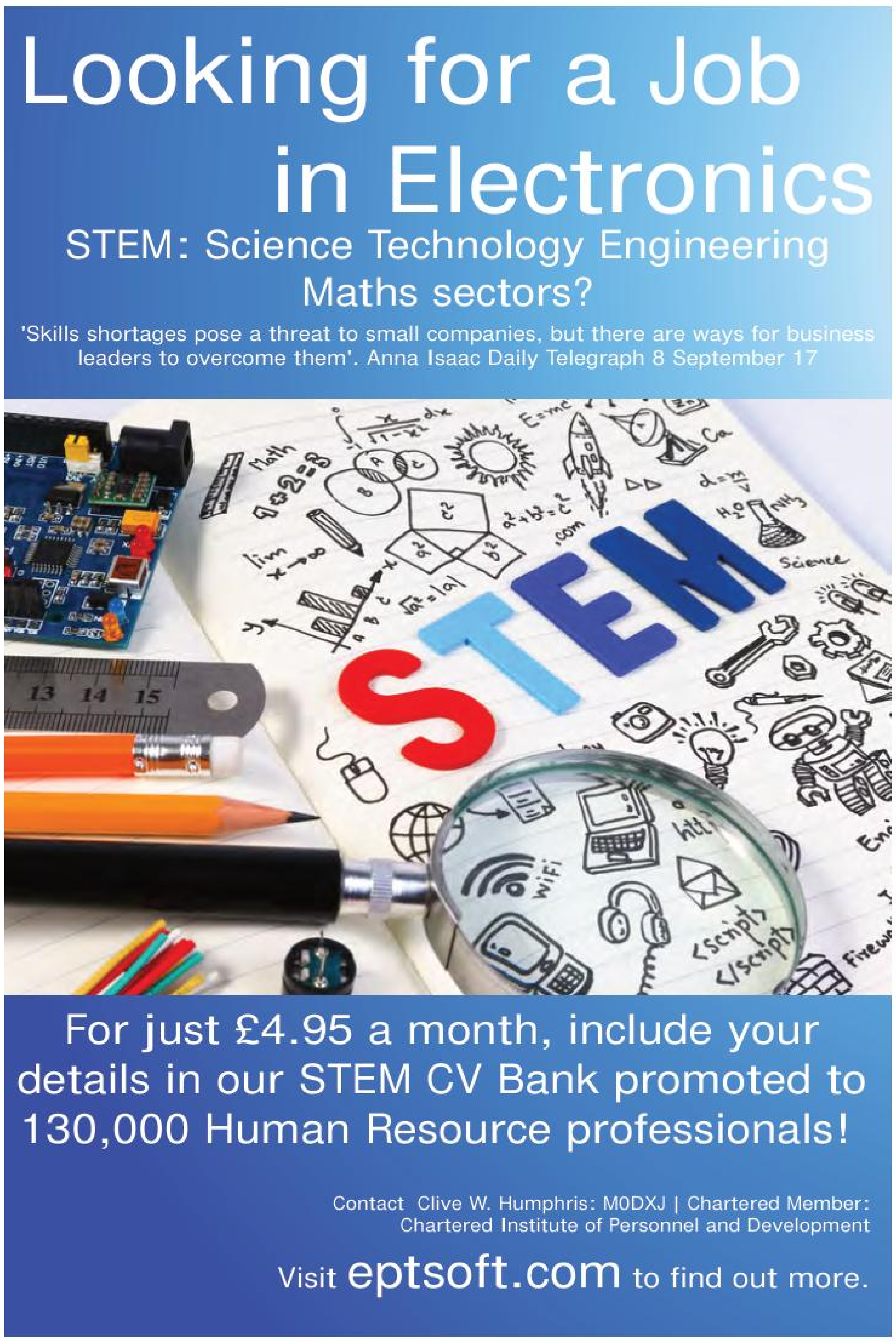
It's nice to take a step back from projects and take a look at other features in the MPLAB X IDE that could potentially make everything a little easier. There is a wide variety of plugins to play around with in the IDE, and I recommend checking them out and see if they work for you.

I hope to use the Code Configurator at the start of future projects, so that we can focus on implementing more complex features inside our projects. The plan for the next few months is to build a number of small projects that can be brought together to create a PIC-based calculator. Next month, we will focus on getting a four-digit seven segment display up and running.



V_{DD}
R8
10kΩ
J1
MCLR
V_{DD}
V_{SS}
PGD/RA0
PGC/RA1
NC
C1
100nF
R9
10kΩ
C5
100nF
S1
1
V_{DD}
V_{SS}
20
2
RA5
RA0
19
3
RA4
RA1
18
4
MCLR
RA2
17
5
RC5
RC0
16
6
RC4
RC1
15
7
RC3
RC2
14
8
RC6
RB4
13
9
RC7
RB5
12
10
RB7
RB6
11
R1
220Ω
D4
R2
220Ω
D3
R3
220Ω
D2
R4
220Ω
D1
R5
330Ω
IC1
PIC16F1829
VR1
10kΩ
R6
330Ω
R7
820Ω
J2
C2
330nF
C3
68nF
C4
68nF
+
BZ1
0V

Fig.3. Schematic for the Simple PIC Sinewave Generator using PIC16F1829



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CIRCUIT SURGERY

REGULAR CLINIC

BY IAN BELL

Temperature sensors – Part 2

LAST MONTH, we started looking at temperature sensors in response to a letter to *EPE* from Ewan Cameron (published August 2017) suggesting topics of interest related to PIC microcontrollers, including accurate temperature sensing. The focus of our discussion was on the sensors and associated circuitry, rather than the microcontroller coding aspects of such a systems. However, we outlined in very general terms what the microcontroller has to do – read the analogue temperature value via an analogue-to-digital converter (ADC) and perform a calculation to obtain the temperature value on the required scale. The calculation may be simple or involve more complex calibration corrections to increase accuracy.

Last month, we also discussed the possible temperature scales, that is, Celsius, Fahrenheit and kelvin. Finally, we introduced various electronic sensor types: thermistors, thermocouples, resistance temperature detectors (RTDs) and IC temperature sensors. We discussed their basic characteristics, advantages and disadvantages. Now we will look in more depth at the key measurement sensors – ICs, thermistors, thermocouples and RTDs – focusing on circuit design. Using raw rather than integrated sensors will typically involve developing and constructing more circuitry, so for accuracy requirements at, or less stringent than around ±1°C, over temperature ranges within about –55°C to 150°C, I recommend using one of the many integrated sensors chips which will usually be more convenient. We will look at these devices in the first half of this month's article.

Complexity

Achieving greater accuracy and range than what is available from integrated sensors is not simply a matter of plugging in a thermocouple or RTD instead of using an analogue temperature IC. The circuits are more complex and, as with any precision measurement system, both good circuit design and good construction practice are required to achieve high accuracy. Furthermore, these sensors are not perfectly linear, and to achieve the best possible accuracy this non-linearity must be compensated for, typically in software. There is a trade-off between accuracy and circuit and software complexity (and processing power requirements). Thus, there is a wide range of possible circuit/software implementations for thermistor, thermocouple and RTD-based temperature measurement. The design of thermocouple measurement systems requires some understanding of the principles of thermocouples and that will be the focus of the latter part of this article. Next month, we will look at thermocouple and RTD circuits.

As we mentioned last month, temperature sensor ICs fall into two main categories – those that output an analogue signal (usually voltage) directly related to temperature and those with digital interfaces. The latter are particularly convenient in microcontroller systems with relatively undemanding accuracy and range requirements. Various temperature ICs with standard bus interfaces (such as SPI bus) are available. (Of course, analogue-output sensors can be used in circuits that do not require an MCU or any code to be written; for example, analogue temperature switches and controllers.)

Analogue IC temperature sensors

Perhaps the best-known analogue-output integrated temperature sensor is the LM35. The LM35 is a three-terminal device which has two power pins and an output pin producing a voltage that varies linearly with temperature at 10mV/°C. There are a large range of similar devices – some with similar part numbers such as LM34, TMP36 and LM335. These devices vary in various ways; for example, the temperature scale, supply voltage range, and presence, or otherwise, of a power-saving shutdown pin. Most devices are aimed at the Celsius scale, but the LM34 provides a 10mV/°F output.

Even with a given basic part number, such as LM35, there are quite a few variants with different packaging (such as TO92, TO220, TO46, SOT and SOIC), different accuracy ratings and different temperature ranges – not all devices provide the full datasheet headline range and accuracy. This diversity means that care must be taken when ordering parts. Some variants are significantly more expensive than others.

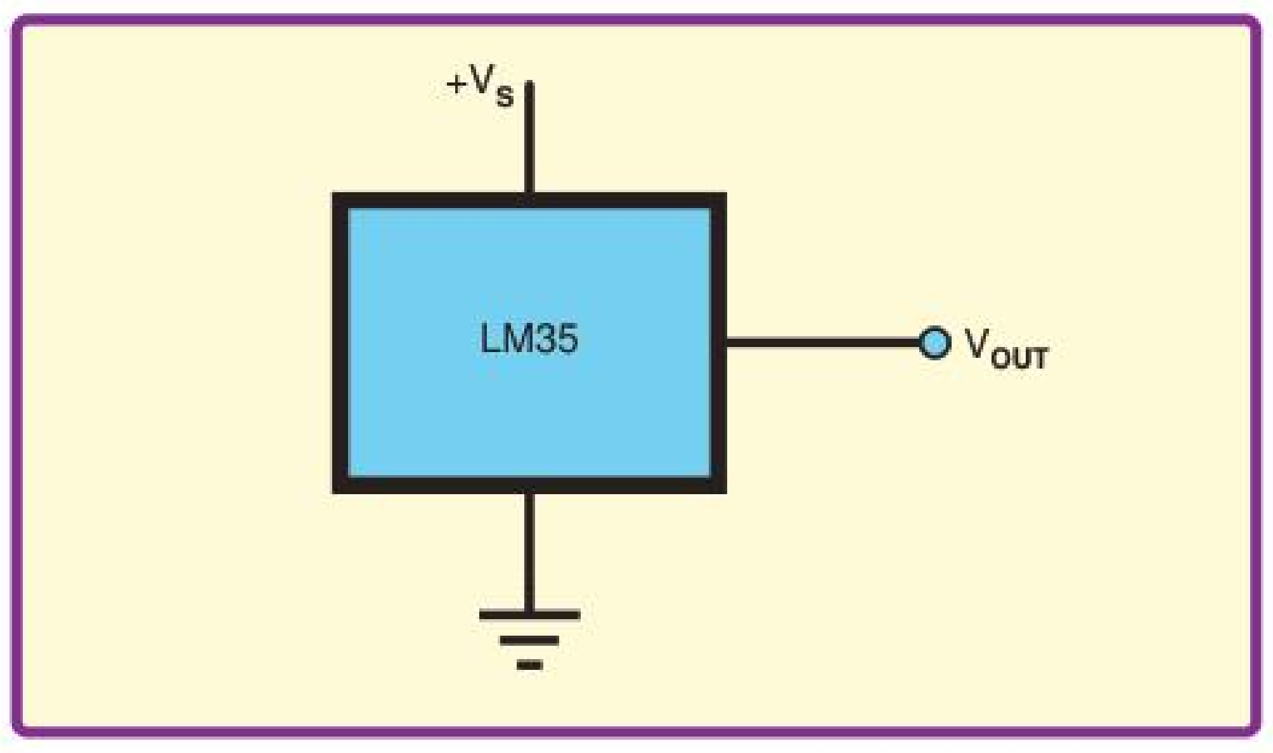

Fig.1. Basic LM35 circuit (based on Texas Instruments datasheet)

LM35 circuits

The most basic LM35 circuit is shown in Fig.1. This provides a 10mV/°C output over the range 2°C to 150°C (20mV to 1.5V out). Notice that the lower end of the LM35's temperature range is not covered because the output of the LM35 cannot go negative in this circuit. The solution is to use a negative supply in the system and wire the LM35 as shown in Fig.2. The LM35 can only source current (current flows out, not in), but with resistor R1 connected to a negative supply a sourced current can result in an output voltage of either polarity with respect to ground. The value of R1 is specified in the LM35 datasheet as $V_S/50\mu A$.

If a negative supply is not available, the circuit shown in Fig.3 can be used. The diodes raise the voltage at the ground pin of the LM35 above 0V (system ground) so the system ground is like a negative supply from the perspective of the LM35. The approach used in Fig.2 can then be applied. It may be tempting to assume the diodes drop about 0.6V or 0.7V (the typical assumption), but the LM35 may only be consuming 60µA, and at these current levels the 1N914 forward drop is in the range 0.45V to 0.5V. If we assume 0.9V total, then the calculation for R1 in Fig.2 gives the datasheet value for R1 of 18kΩ.

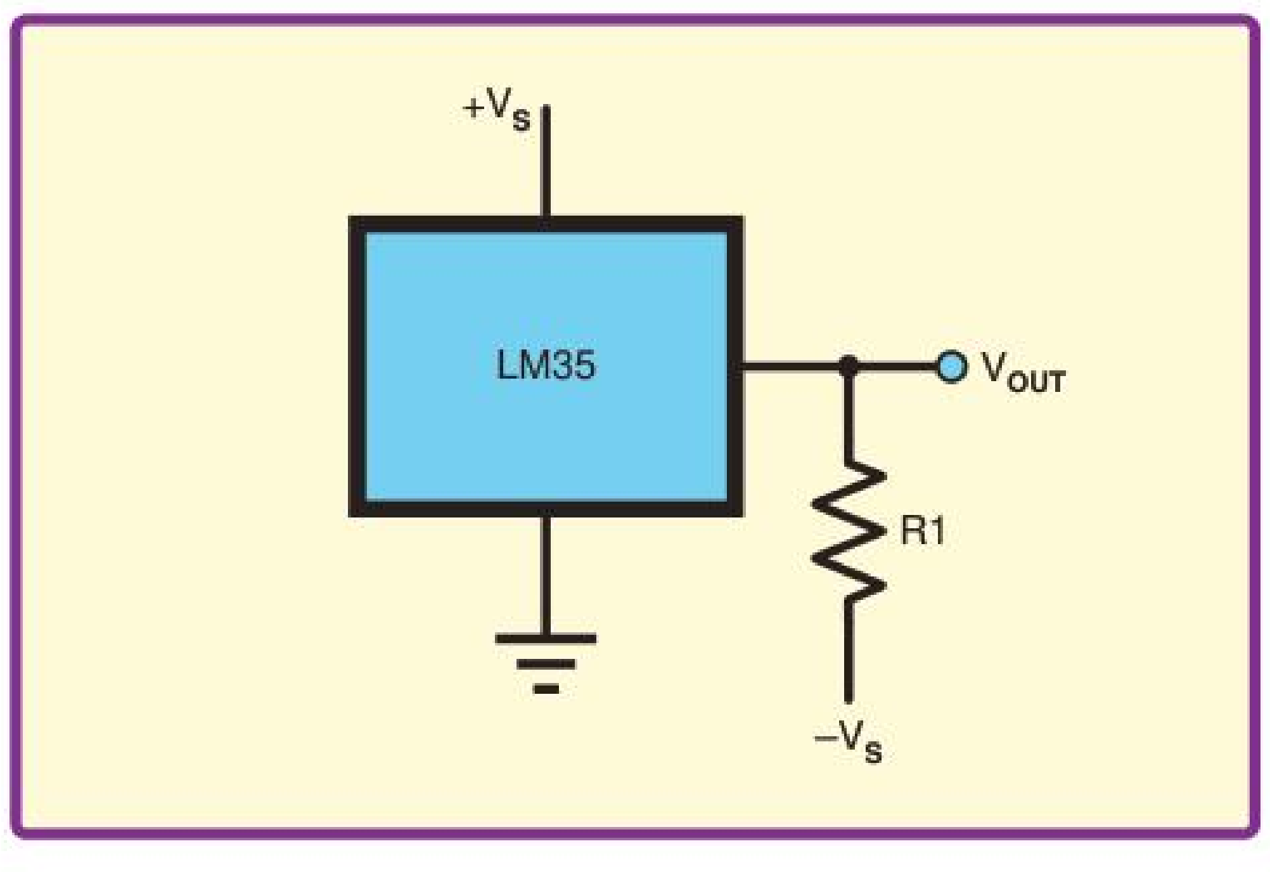

Fig.2. Full-range LM35 circuit (based on Texas Instruments datasheet)

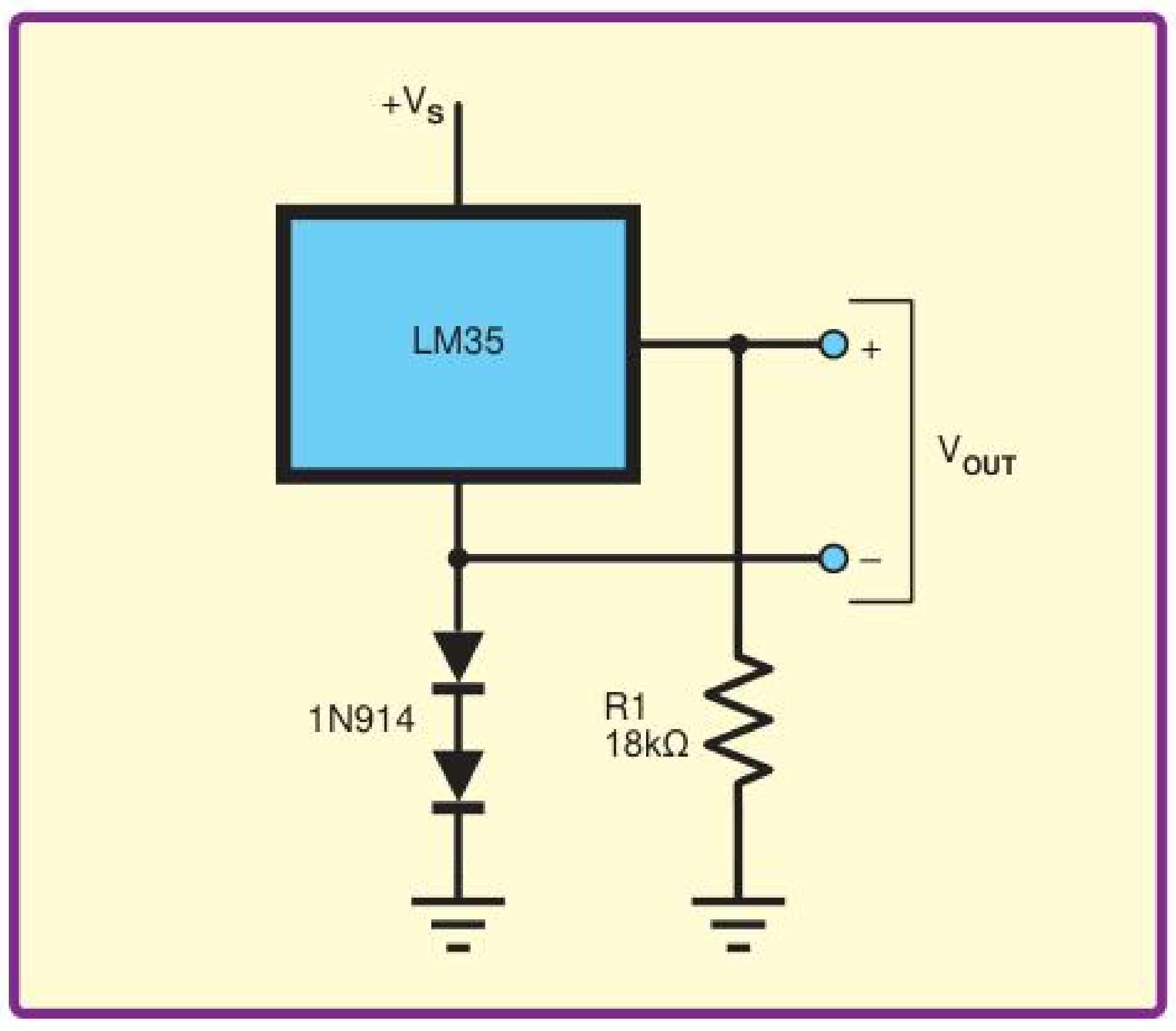

Fig.3. LM35 range extension on a single supply (based on Texas Instruments datasheet)

The circuit in Fig.3 differs from the one in Fig.2 in that the output voltage is not referenced to ground. Various approaches to dealing with this are possible. Just the normal output pin of the LM35 could be used, on the assumption that the diode drop is constant, subtracting this to get the temperature voltage, but this is very likely to be inaccurate as the diode drop will change (eg, with temperature and LM35 supply current). Better approaches are to use the differential output (as shown) with a differential input amplifier, a differential input ADC, or to measure both voltages separately (eg, using multiple ADC channels) and subtract in software.

Other ICs – TMP36

The circuit in Fig.3 is not very convenient, so a better approach with a single supply is to use a different chip, which can measure negative temperatures on a single supply. Examples include the TMP36 from Analog Devices and the LM50 from Texas Instruments. These devices have a 10mV/°C output, like the LM35, but with a +0.5V offset (so output 0.5V at 0°C, 0.75V at 25°C and 0.25V at –25°C) which facilitates output of voltages representing negative temperatures. An example circuit for the TMP36 is shown in Fig.4. Note the shutdown pin, which is available on some package options.

The devices just described are not the only options with analogue output. Other examples include the LMx35 series (x is 1,2,3) which are like zener diodes with breakdown voltages directly proportional to absolute temperature at 10mV/K (note kelvin scale). The LM135 covers a range of –55°C to 150°C. There is also the AD950, which is another two-terminal device. This has a linear current output of 1µA/K (again a kelvin scale) with a supply of 4V to 30V over a measurement range of –55°C to 150°C.

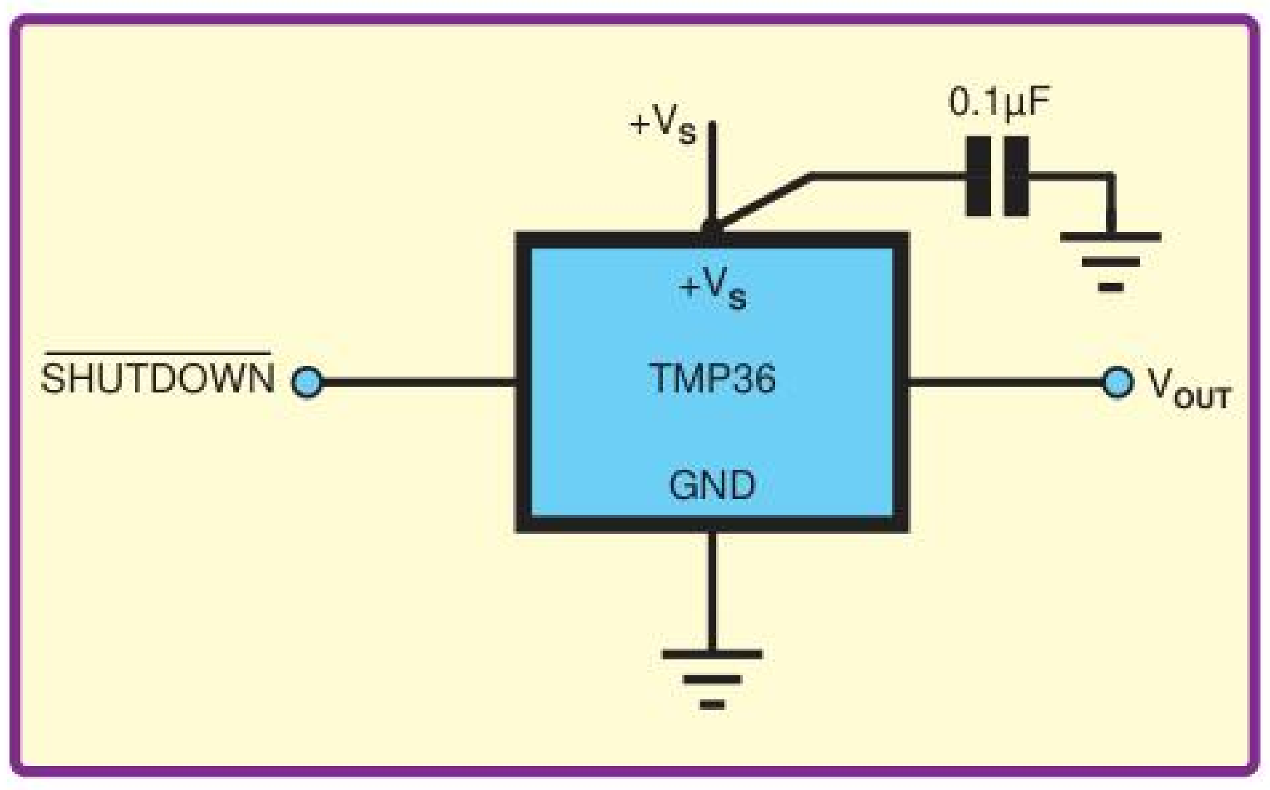

Fig.4. TMP36 circuit with –40°C to +125°C range (based on Analog Devices datasheet)

Long leads

It is not uncommon to need to locate a temperature sensor away from the main circuit board. This may make the sensor wiring susceptible to noise pick-up from various sources. Fortunately, in most situations temperatures change relatively slowly and appropriate low-pass filtering can reduce noise without excessively impacting the measurement process. As usual, shielded and/or twisted pair cable should also be used for lengthy sensor connections to reduce the amount of noise pickup.

Another issue with long sensor connections, which should not be overlooked, is the capacitance of the cable. Some circuits driving high capacitance loads may be susceptible to instability, as was discussed in *Circuit Surgery* in the February 2015 and December 2016 issues. It was noted in those articles that a common solution is to use an isolation resistor between the output and capacitive load. The capacitive drive capability varies significantly for different integrated analogue temperature sensors, but in general the series resistor approach is applicable (see Fig.5) and sensor datasheets may provide advice on appropriate values (this is the case for the LM35 and TMP36). Alternatively, an RC damper may be used (see Fig.6). The series resistor, plus cable capacitance, or a damper circuit, also forms a low-pass filter, assisting reduction of noise.

Finally, as with many integrated circuits, it is often a good idea, or even essential, to connect one or more supply decoupling capacitors as close as possible to the sensor IC. A typical value is 0.1µF (100nF), but the datasheet should be consulted for the most appropriate value and just as important, capacitor types. The circuits in Fig.5 and 6 show typical circuits for using temperature sensors on long cables. In more extreme situations (very long cables, high electrical noise) converting the sensor voltage to a current for transmission down the cable may be a better approach.

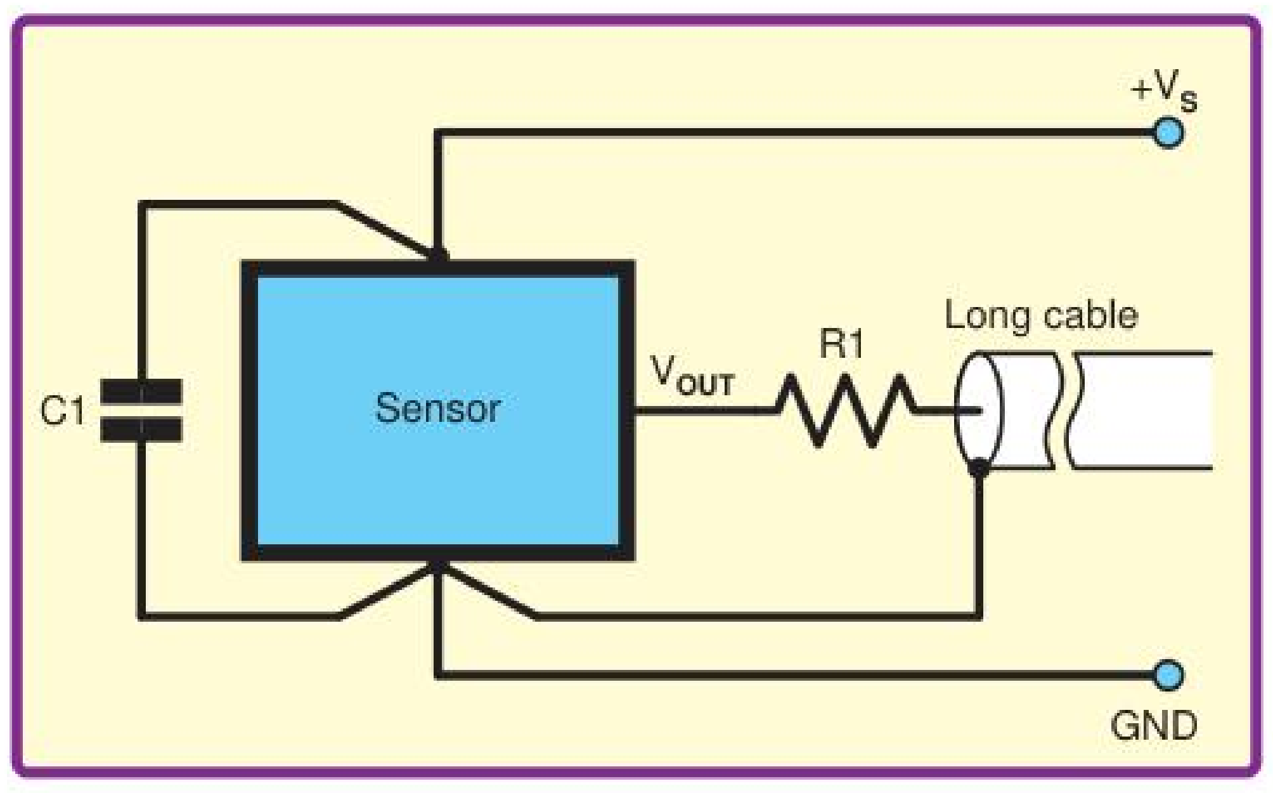

Fig.5. Analogue integrated temperature sensor on long cable with decoupling capacitor C1 and load capacitance isolation resistor R1.

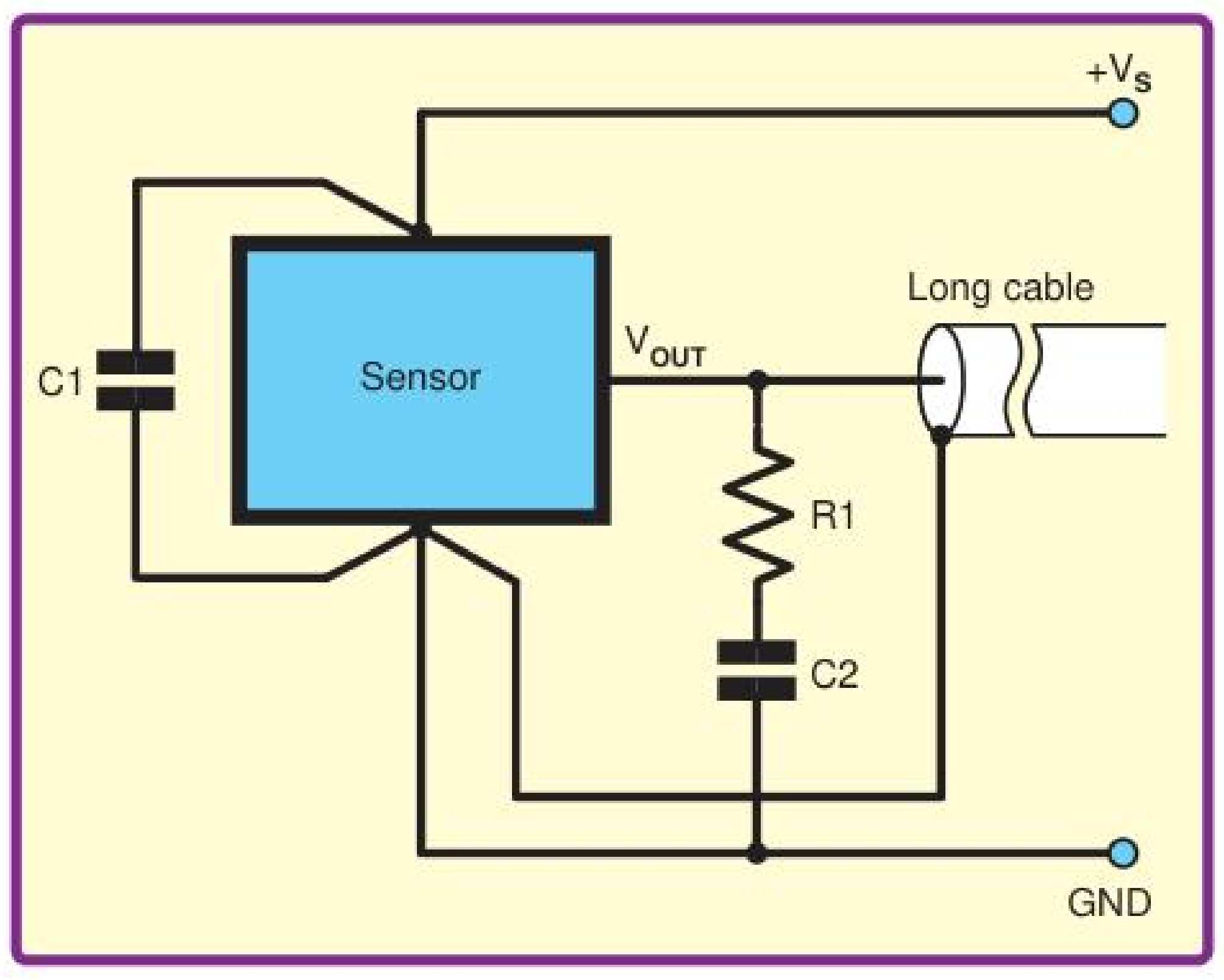

Fig.6. Analogue integrated temperature sensor on long cable with decoupling capacitor C1 and RC damper (R1 and C2).

ADCs

In a typical microcontroller (MCU) system the voltage output from the devices just discussed will be connected to an ADC for conversion to a digital value. For the system to make best use of the sensor, the ADC, which may be on the MCU chip or external, must be set up correctly. This includes setting the reference voltages that determine the ADC's conversion range. The output voltage range from a typical temperature sensor may be smaller than the default input range of the ADC; so if the ADC range is not adjusted the full ADC resolution will not be utilised. Correct ADC setup is also important when using other analogue temperature sensors, such as thermocouples and RTDs.

Digital IC temperature sensors

An alternative to setting up the ADC yourself is to use a temperature sensor with a digital interface. Examples of digital integrated temperature sensor ICs with SPI-type buses include the LM74 from Texas Instruments, the TC77 from Microchip, the ADT7301 from Analog Devices and the MAX6662 from Maxim Integrated. These all have similar accuracy specifications of around ±1°C for their 'middle' temperature ranges of, say, –10°C to +50°C, rising to around ±3°C for larger ranges, such as –55°C to +125°C. This is just a typical accuracy summary, the detailed individual specification of different devices do vary, so potential users should, as always, check the datasheet. SPI is not the only common bus of course, and integrated temperature sensors with other interfaces, such as I^{2}C, are also available.

SPI temperature sensors such as those listed above, typically have about 5 or 6 pins in use (others will be no-connection (NC), for example on an 8-pin package). There will be two power pins and three or four pins for the serial interface. The MAX6662 features two extra pins which provide a programmable high and low temperature alert – typically these would be used to trigger microcontroller interrupts. Few additional components are needed with such devices. Usually, a supply decoupling capacitor is required or recommended, with this being particularly important if the sensor is mounted remotely from the main circuit board and power supply. In some cases, resistors will be needed on one or more bus lines. This depends on the exact formats of the microcontroller and device buses, and guidance will usually be found in the datasheet. An example of the wiring of an SPI bus integrated temperature sensor and microcontroller is shown in Fig.7.

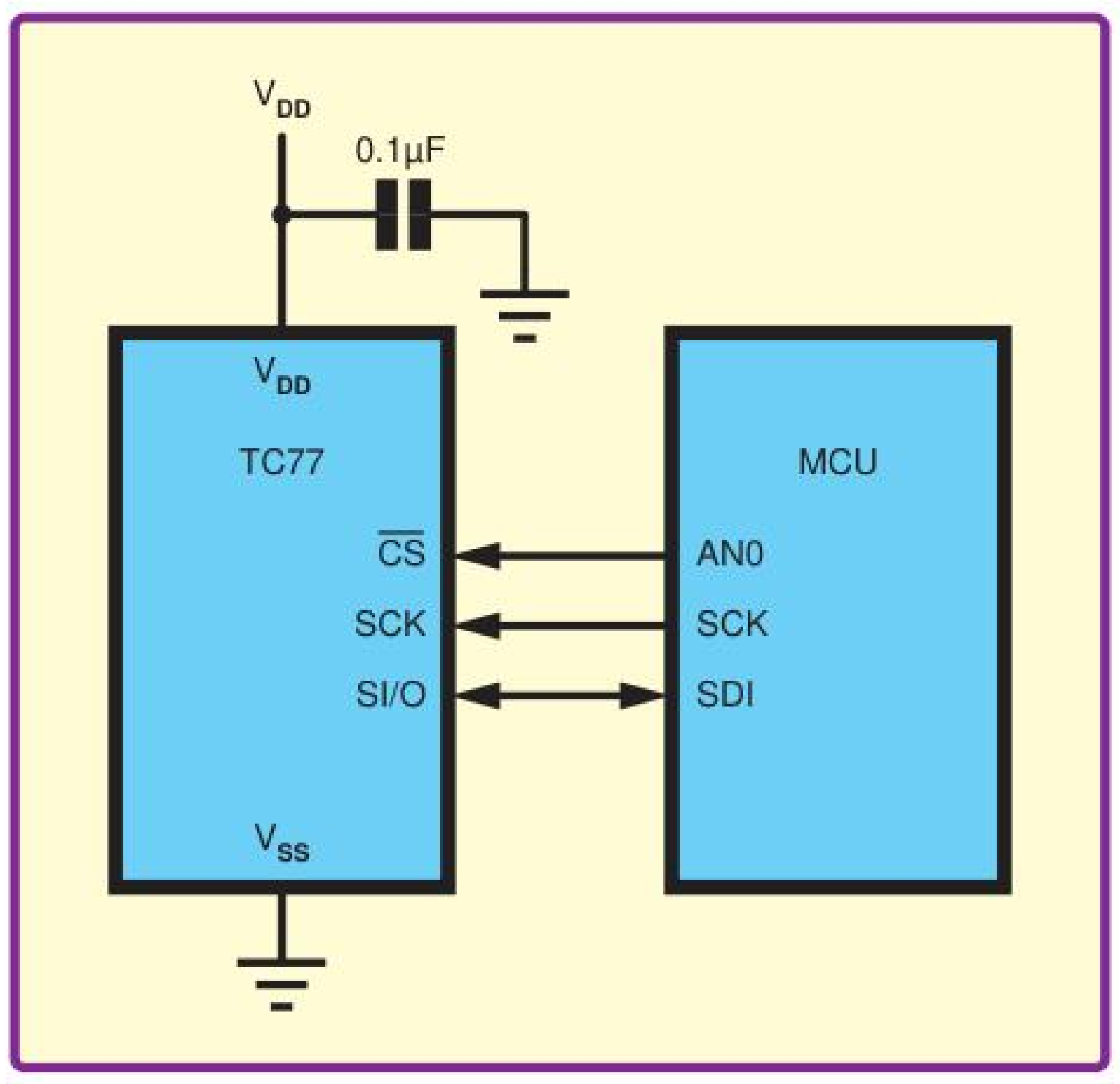

Fig.7. Example SPI bus integrated temperature sensor: connecting a TC77 to a PIC microcontroller (based on Microchip datasheet)

Accuracy and range

The accuracy of the integrated sensors discussed so far is typically around ±1°C, to about ±0.2°C at best, and the maximum measurement range is typically around −55°C to +150°C. The accuracy tends to decrease at the extremes of the measurement range, where it may be more like ±3°C. To measure temperatures outside this range, or with higher accuracy, requires use of different sensor types, with thermocouples and platinum RTDs usually being the best candidates. Thermocouples are able to measure higher temperatures, up to around 1800°C, whereas RTDs are more limited at around 900°C. This does not mean that all sensors of these types that you can buy go to these extremes – the packaging has a big influence on the measurement range, which must be checked when selecting sensors or probes. Thermistors are a (usually) lower-cost alternative, which may provide a little more range than IC sensors and can achieve a bit better accuracy with linearisation in software.

Thermocouples

Last month, we described the thermocouple in simplistic terms as two different metals joined together, generating a potential. To work with thermocouple circuits we need to understand what is happening physically in a bit more detail. The key here is the Seebeck effect, which describes how a metal with a temperature gradient along it will produce an electromotive force (EMF). That is, it will generate voltage difference between the ends at the different temperatures. The voltage produced depends on the temperature difference and a property of the metal called the Seebeck coefficient. Note this is a *generated* voltage, not a voltage drop as one would get from a temperature-dependent resistor with an applied current – hence the use of the term 'EMF'.

If a single conductor is connected to form a circuit (loop) with sections at different temperatures then there will be equal and opposite temperature gradients which produce EMFs which cancel out. However, if a conducting loop has two different metals (with different Seebeck coefficients), with the junctions at different temperatures, then the two EMFs will not be exactly equal and opposite, and a current will flow.

Junction

We can also look at the open-circuit case with different conductors, as shown in Fig.8. The different material wires are joined at one end, so they are electrically connected and at the same temperature. The other two ends are not connected to anything, but are at the same temperature as one another. The Seebeck effect means that each wire will generate an EMF. Given that the temperature difference is the same in both cases there will be a voltage across the open circuit *if the EMFs are different*, which will occur if the Seebeck coefficients of the metals are different.

The larger the difference in Seebeck coefficients the larger the voltage. This is the basis of the thermocouple – the difference in Seebeck coefficients when two different conductors are joined in this way results in a voltage difference. The EMF is produced along the wires, not by the junction, but looking at the open circuit voltage it may seem like a junction of different conductors is responsible for producing the voltage, so thermocouples are often described as if the junction itself generates the EMF.

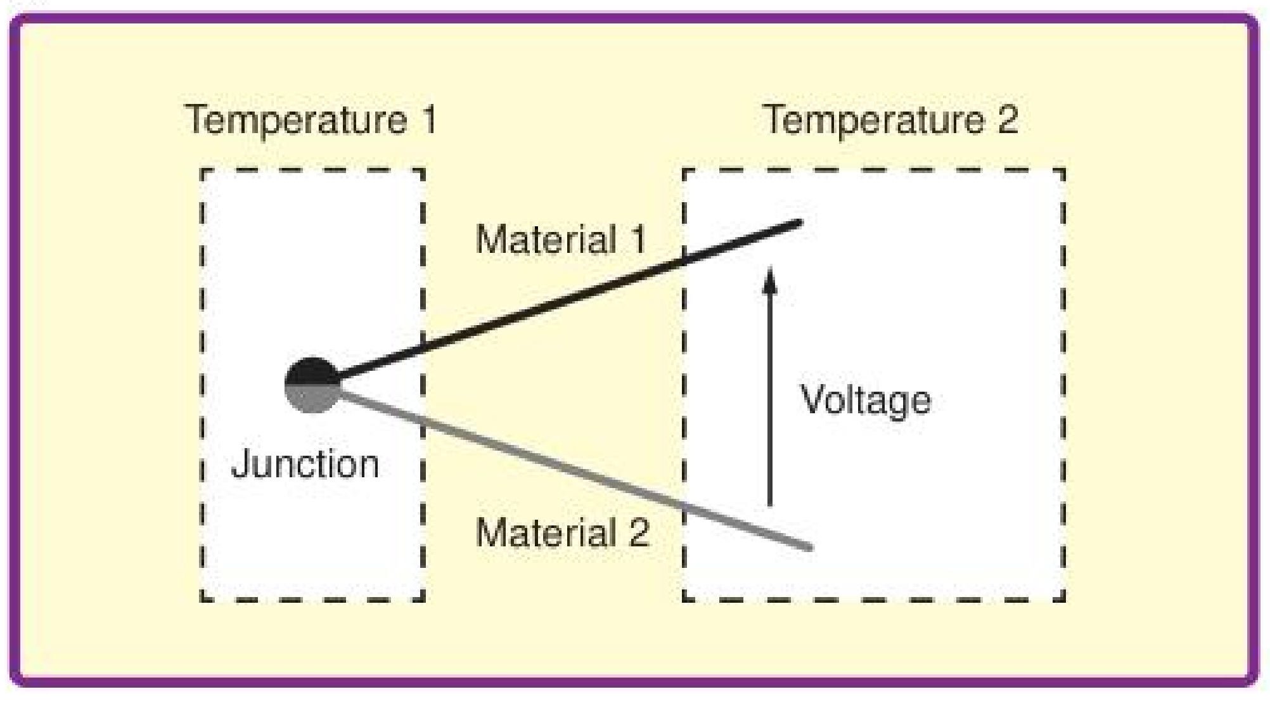

Fig.8. The fundamentals of the thermocouple: two different conducting materials, joined at one end, with the same temperature gradient along them will both generate a voltage difference between the other ends determined by their relative Seebeck coefficients

There is a choice of internationally standardised thermocouples which use specific materials for the two conductors (materials 1 and 2 in Fig.8). These are identified by a letter, for example K-type thermocouples use chromel (a nickel/chromium alloy) and alumel (nickel/aluminium/manganese) and have measurement range of −200°C to 1250°C. Their Seebeck coefficient is around 40µV/°C at 20°C (the relative coefficient, dependent on the two different materials). As was mentioned earlier, the response of thermocouples is not linear, or to put it another way, their Seebeck coefficients vary with temperature. K-type thermocouples are popular because they are more linear than most other types, at least over a substantial part of their range.

Measurement system

Fig.8 is somewhat abstract in that no circuitry is connected to the open circuit end. If we connect some circuitry to make measurements then we create more junctions, as shown in Fig.9. Usually, the materials of the actual thermocouple (material 1 and 2 in Fig.8 and Fig.9) are selected to give a relatively large voltage over the desired temperature range, whereas material 3 (Fig.9) will typically be the copper of PCB tracks or normal connection wiring. The possibility exists of thermal gradients and hence Seebeck effect EMFs along the copper wiring of the measurement system, however, with reference to Fig.9, assuming the two copper wires have the same temperature gradient (from temperature 2 to 3) the generated voltages will be equal and opposite and not affect the measurement. This assumption requires the two junctions between the copper and thermocouple materials to be at exactly the same temperature.

Maintaining equal temperature of junctions 2 and 3 (Fig.9) is important in the construction of thermocouple instruments and the physical structure used to ensure this is referred to as an isothermal block. Implementation techniques include keeping junctions 2 and 3 physically close, using relatively large amounts of metal for the connection (for example large terminals and copper fill on PCBs), keeping the junctions away from heat sources (such as relatively high power components), and preventing air currents from circulating around the junctions using suitable enclosures.

The voltage from the thermocouple in Fig.8 and 9 is dependent on the difference between temperatures 1 and 2, not the absolute temperature of junction 1 – this is the general case with thermocouples – they measure temperature *difference.* The basic approach to measuring absolute temperature is to hold one junction at a fixed known temperature so that

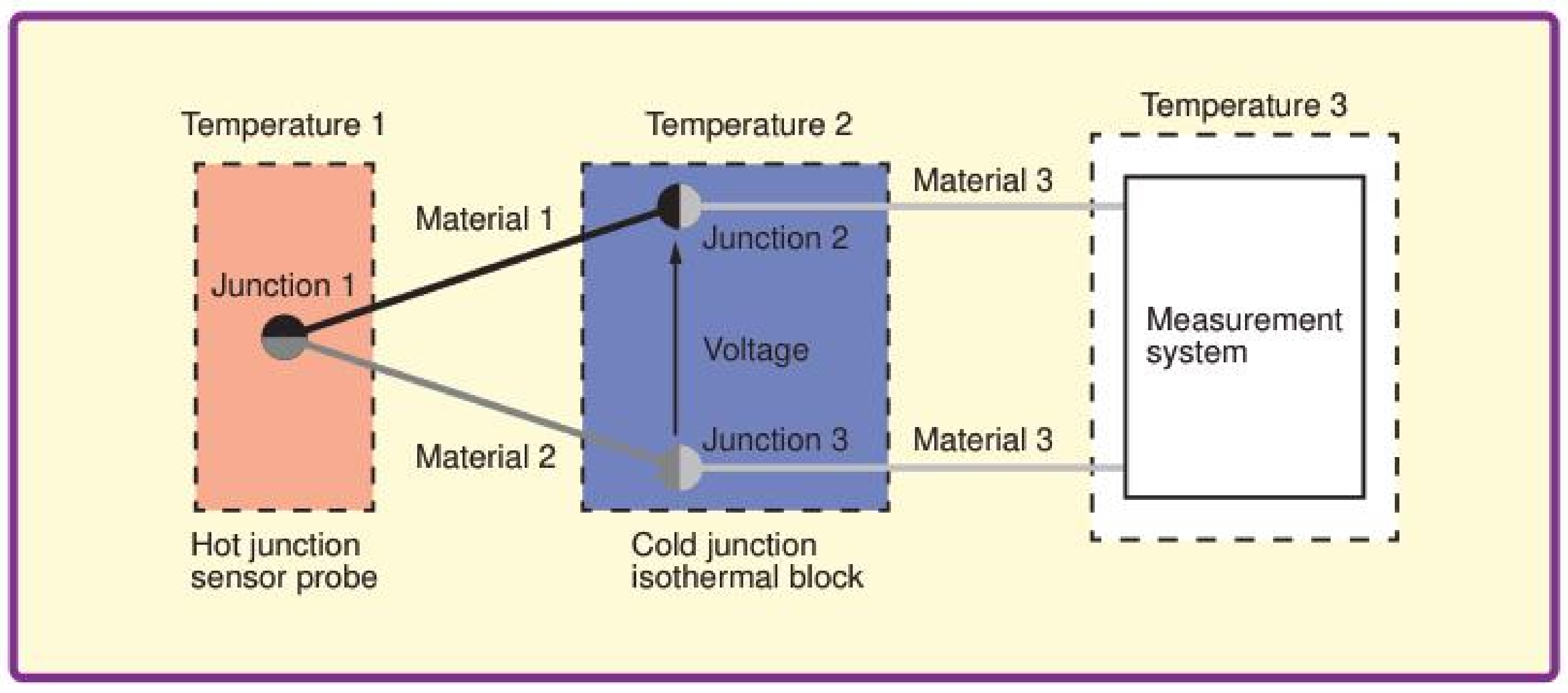

Fig.9. Structure of a thermocouple-based temperature measurement system.

variations in the voltage generated are dependent only on the temperature of the other junction. The system can then be calibrated to measure with the required temperature scale. In a classic laboratory experiment the fixed temperature would be 0°C obtained using iced water, thus this reference junction is often referred to as the ‘cold junction’ and the junction used for measurement is the ‘hot junction’. However, the reference does not have to be at 0°C, does not have to involve ice (not convenient for most measurements!) and does not have to be colder than the measured temperature – but you do need to know what temperature it is.

Cold-junction compensation

In a typical electronic thermocouple instrument the cold junction is the isothermal block (which actually contains two junctions) and the hot junction is the sensor probe (as in Fig.9). The cold junction will usually be at room temperature (in the instrument) and consequently may vary in temperature, affecting the measurement. For measuring very large temperatures (where cold junction temperature variation is comparatively small), without very high accuracy requirements, this may not matter, but in many situations something has to be done to address this – a process known as ‘cold junction compensation’.

Cold junction compensation involves measuring the temperature of the cold junction/isothermal block, which can be done using an integrated sensor IC (as discussed earlier), thermistor or an RTD. The signal from this measurement can then be used to correct for the cold junction temperature variation in software, or it can be used in a variety of analogue cold junction compensation circuits. One general approach is to apply an offset voltage directly to the cold junction which is equal to its temperature in °C scaled by the (relative) Seebeck coefficient of the thermocouple. The compensation voltage polarity is opposite to that of the thermocouple. This results in an overall output voltage which behaves as if the cold junction was at 0°C (so the compensation voltage is zero at 0°C).

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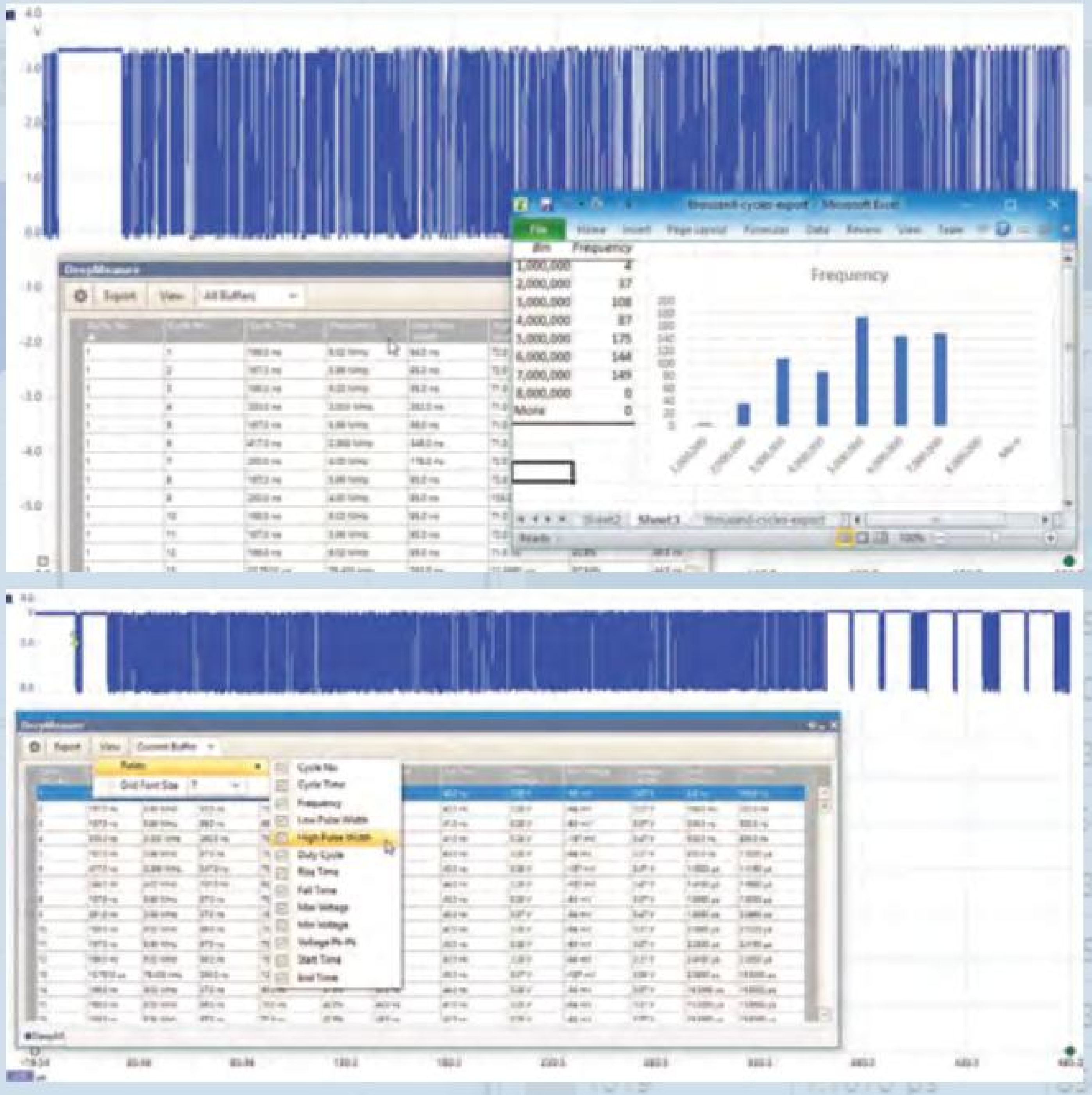

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AUDIO OUT

By Jake Rothman

MX50 power amplifier circuit tweaks – Part 1

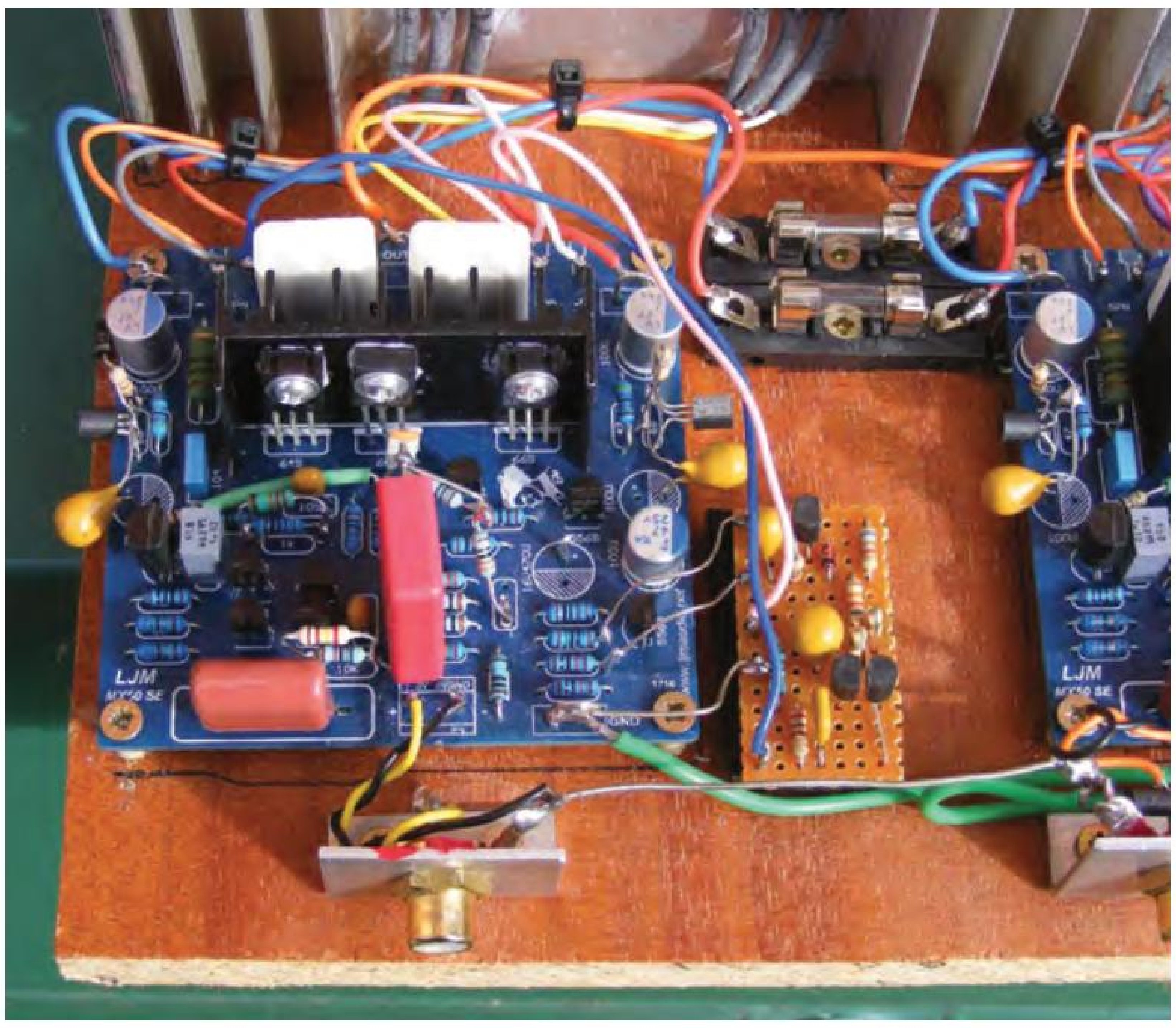
Fig.1. Modified MX50 – I've reached the stage where a new PCB is needed – one day!

Following on from May and June's column, where I looked at the MX50 power amplifier, here I offer some useful esoteric tweaks for those who are interested in upgrading this flexible kit, or indeed any power amplifer.

In modifying the MX50, my main objective was to reduce the number of wet electrolytics to just two. Generally speaking, these types of capacitors have a short life, especially at high temperatures. The power supply capacitors are the only ones remaining, but fortunately these are much longer lasting because they're big. Also, the gain has been reduced to suit the Baxandall active volume control pre-amplifer (see *Teach-In 2015*, *Part 5-6*, *EPE*, Jun-Jul 2015). This volume control topology has +16dB (6x) gain, which has to be accommodated by reducing the power amplifier gain. Lower than normal gain is also necessary for active speaker systems to minimise hiss from preceding filters by allowing them to be run at a higher level. This also applies if a balanced input stage is used. A photo of the modified MX50 amplifier is shown in Fig.1.

Capacitor distortion

The most difficult electrolytic to eliminate in any power amp is the lower-arm feedback capacitor. This is C3 in the MX50. I've recently built a new distortion analyser and solid capacitors (such as polymer and tantalum) distort ten-times more than 'normal' electrolytic ones. The basic test set-up is shown in Fig.2. Tantalum distortion residuals are shown in Fig.3a and Fig.3b. This means one can't just replace the capacitor with a tantalum bead unless you are happy for distortion to go up by possibly a factor of ten. Remember, a 100µF film capacitor is impossibly large and costly. Z5U and Y5V multilayer ceramic capacitors are now available in high values up to 47µF and are often suggested as tantalum replacements, but these can't be used in audio because of their intolerable distortion levels (Fig.4). Most capacitor distortion is second and third harmonic and subjectively benign compared to crossover distortion, but it will spell commercial disaster in a review. Since this amplifier is to have reduced gain, the signal voltage is higher and consequently also the capacitor distortion.

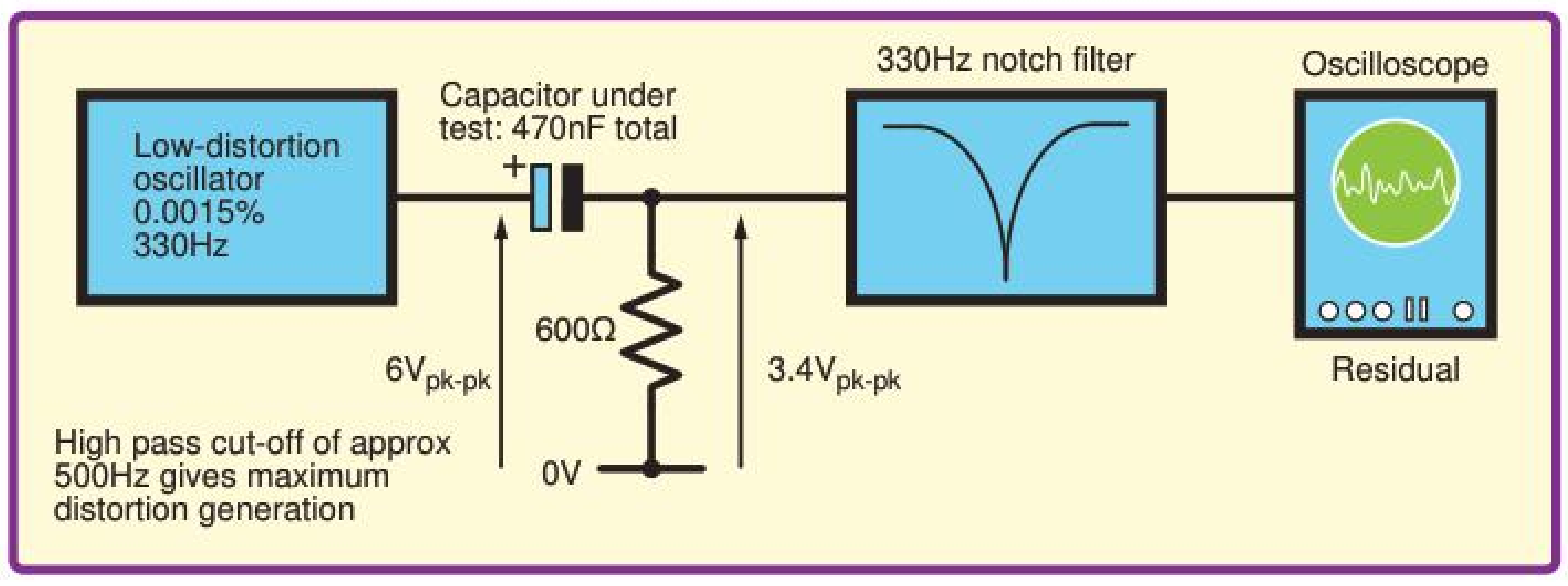
Low-distortion oscillator 0.0015% 330Hz
Capacitor under test: 470nF total
+
330Hz notch filter
Oscilloscope
Residual
600Ω
6V$_{pk-pk}$
3.4V$_{pk-pk}$
0V
High pass cut-off of approx 500Hz gives maximum distortion generation

Fig.2. Distortion test set-up for capacitors, similar to the work done by Walter Jung and Richard Marsh in Audio Magazine, Feb and March 1980. The test frequency was 330Hz to make it possible to take full screen photos.

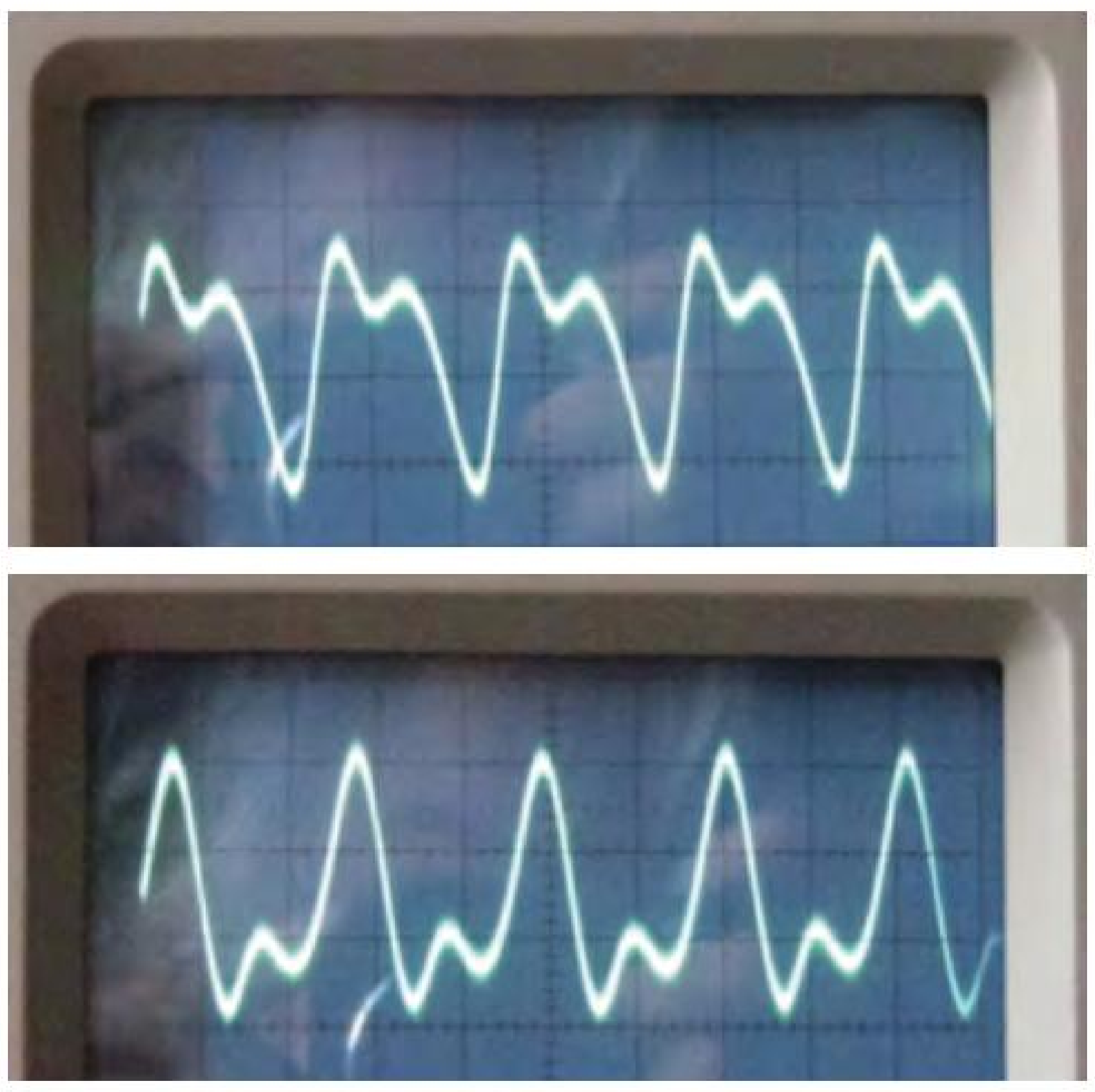
Fig.3a and 3b. Standard 'no-name' green Japanese 1µF 35V tantalum bead capacitor connected one way, then the other. Note how distortion is inverted. THD = 0.013%

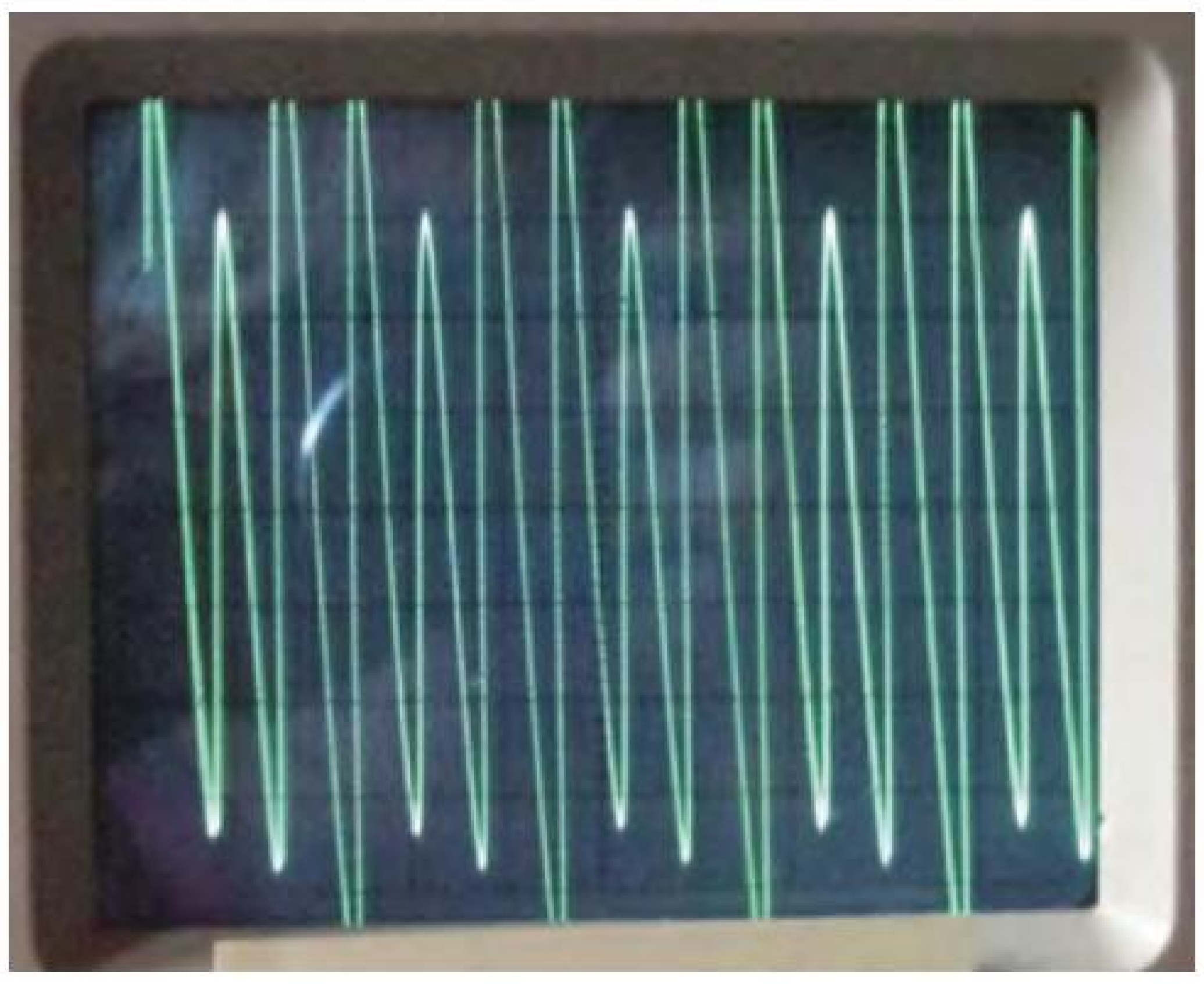
Fig.4. Hi-K ceramic capacitors such as Z5U, Y5V and some X7R types make so much distortion they are unsuitable for Hi-Fi. This Z5U one was a 'no-name' capacitor made in Taiwan.

Polarising tantalum capacitors reduces their distortion (Fig.5), but the MX50 is dual-rail so the DC level is 0V. Putting two tantalum capacitors back-to-back in parallel (Fig.6) gives distortion cancellation. Fig.7 shows a power amplifier

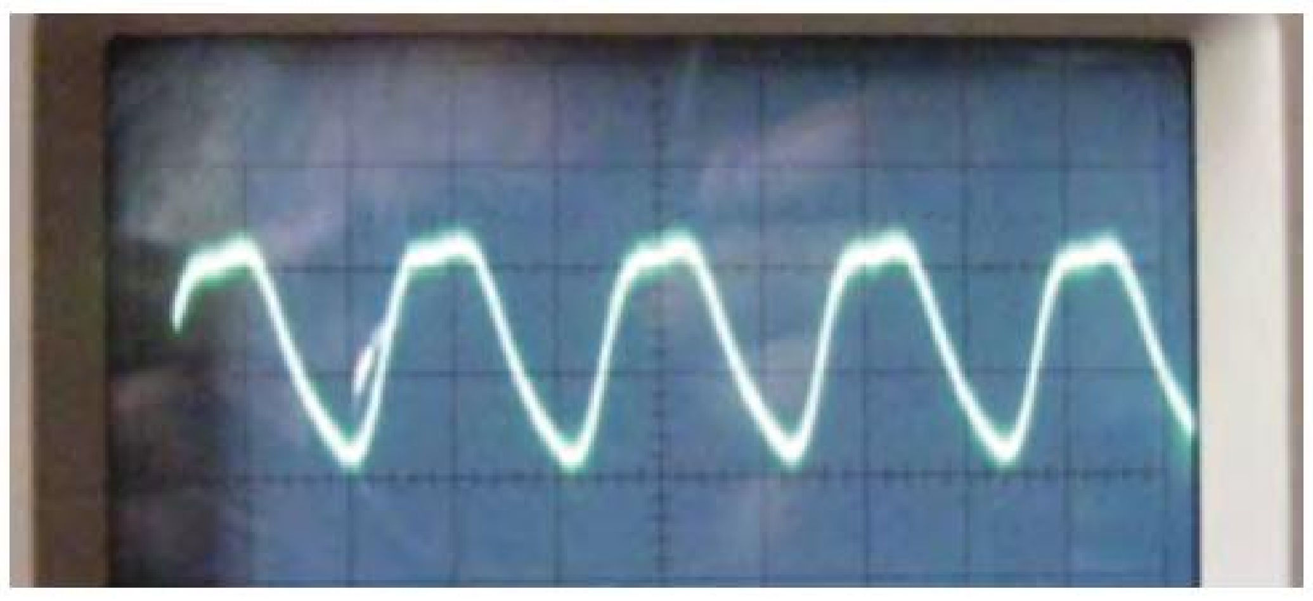

Fig.5. Effect of biasing capacitor – this begins to be effective at 5V and the rate of improvement falls off as 15V is approached (THD = 0.005% at 9V bias).

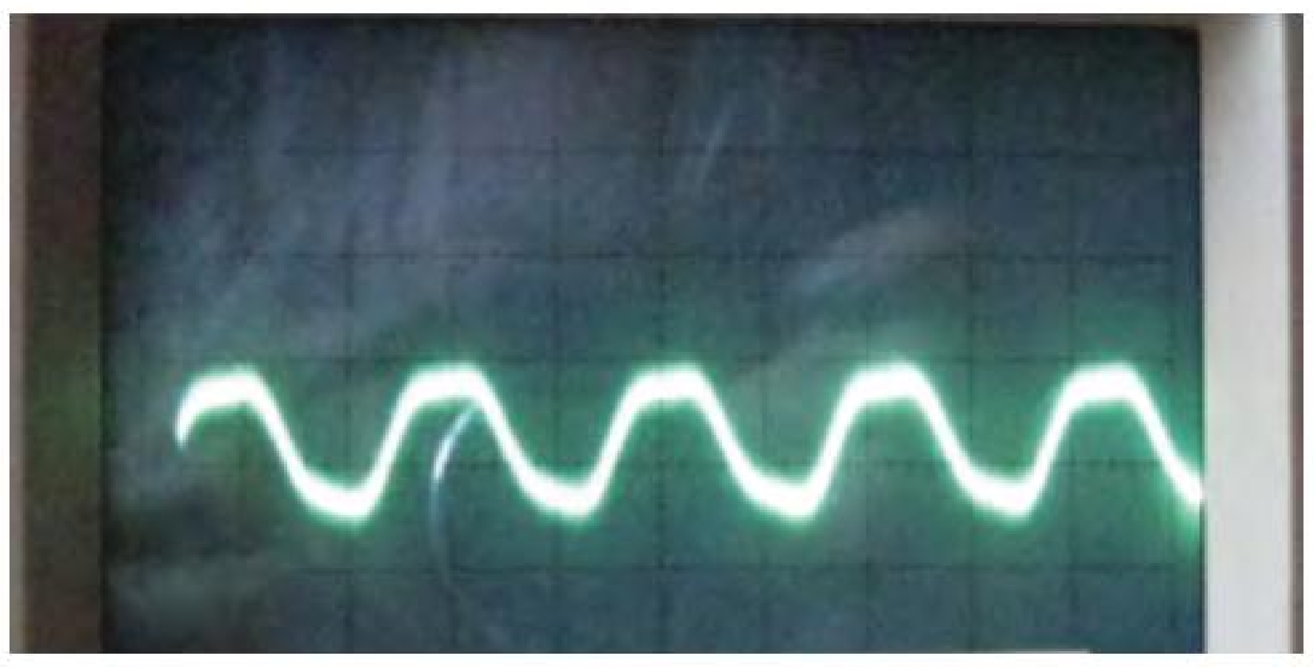

Fig.6. Asymmetrical distortion components cancel when two capacitors are connected back-to-back in parallel. Only suitable for voltages below ±1.5V. Cancellation is dependent on matched harmonic generation from each capacitor (THD = 0.0043%). The effect works just as well with the capacitors in series while retaining full voltage rating.

using the series capacitor connection. However, this means two capacitors of double the value have to be used and tantalum capacitors are expensive. A polarising voltage can now be applied, further minimising the distortion. As with all coupling capacitors, oversizing keeps the cut-off frequencies well below 20Hz and this minimises the signal voltage across them, and brings distortion down by a factor of ten.

Solid polymer capacitors are cheaper, but the cancellation and biasing tricks don't work nearly as well. Their third-harmonic distortion remains unabated. This may be one reason, along with leakage current, that Würth say on their PTHR polymer data sheet, 'not recommended for coupling applications'.

Blow up

Since the feedback capacitor is subject to the same signal voltage as the input, it is common to specify low-voltage components. The one in the MX50 is 16V. If the amplifier's output goes offset, the voltage dropped across the feedback resistor, due to the leakage current through the capacitor prevents destruction. With the back-to-back parallel connection one capacitor protects the other. However, I have found polymer types are able to build up sufficient voltage to fail short-circuit, so full-voltage rating (35V) will have to be used. Putting a Zener diode across the capacitor, as shown in Fig.8 provides protection against overvoltage and reverse polarity. The Zener voltage has to be over 4.7V to avoid additional distortion. For very low voltage capacitors, say the 4V niobium types, a 2.7V Zener in series with a 1N4148 can be used.

It can be seen ceramic, tantalum and polymer capacitors have their problems. Fortunately, there's a solution. The gain-setting potential divider is put straight across the output coupled to the inverting input via a much smaller film capacitor of a few microfarads, as shown in Fig.9. There will be no feedback at DC, so an extra resistor is needed from the output to the inverting input. This has to be quite a high value to avoid causing bass loss in conjunction with the new capacitor. A typical value is 47kΩ. This can't go too high or a large offset may be generated due to the transistor input bias currents. Offset can be minimised by making the non-inverting input pull-down resistor (R3 in Fig.2, *EPE*, May 2017) the same value. Additional trimming may be necessary to get the offset to acceptable levels. I made R3 high at 68kΩ and padded it down with a parallel resistor. With the transistors I used it turned out to be 82kΩ. An alternative is matched input transistors or a dual device, such as the Toshiba HN1A01FU. The –3dB point was 12Hz with a 3.3μF polyester capacitor. Wima make some 5mm-footprint 3.3μF capacitors.

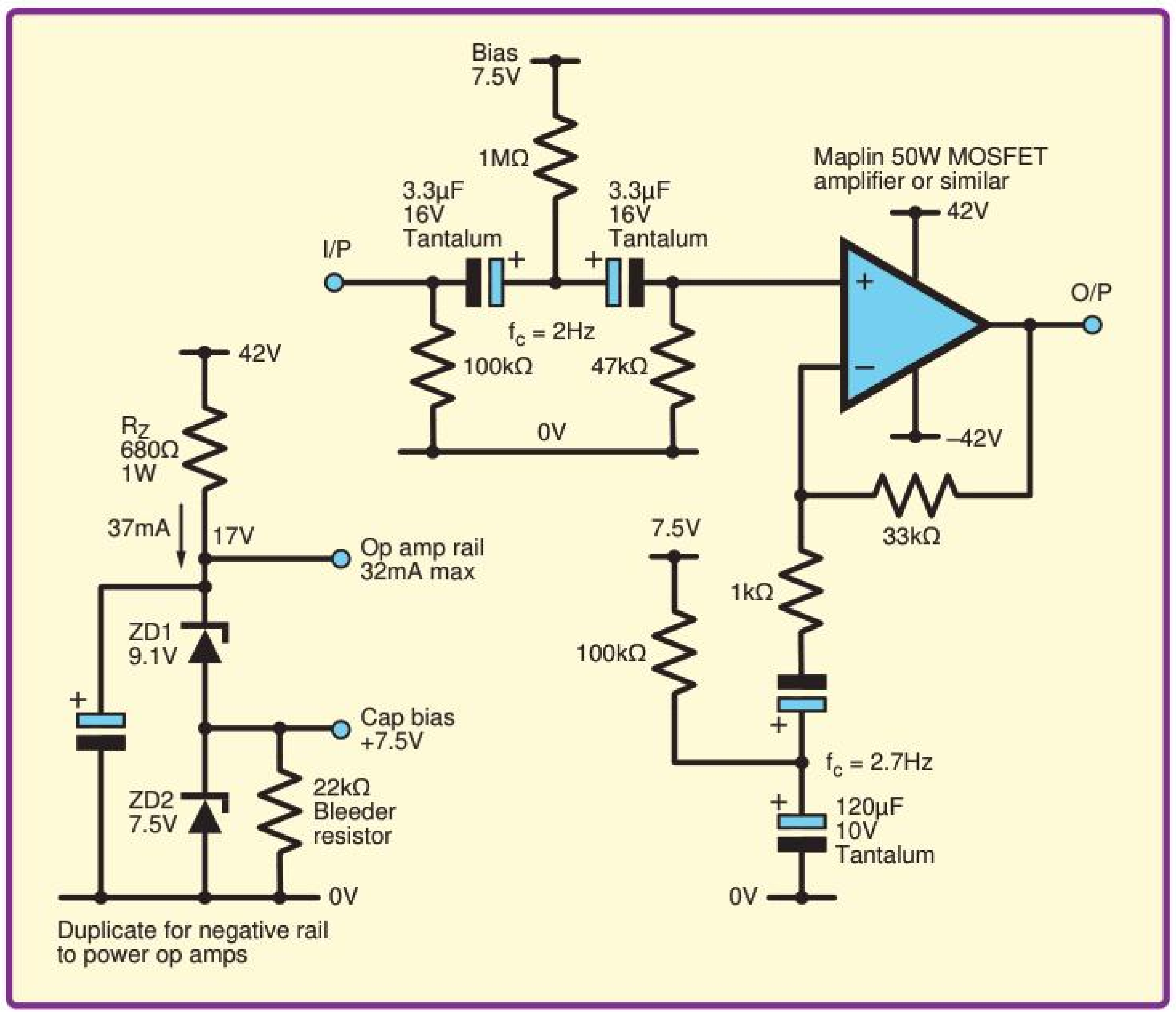

Fig.7. Biased series back-to-back, the most effective passive tantalum distortion reduction technique (THD = 0.003% in the test above). In this case, the low-frequency cut-off is 3Hz. The input capacitors would be replaced by a film type today. Biasing has to be carefully arranged to avoid thumps at turn on/off.

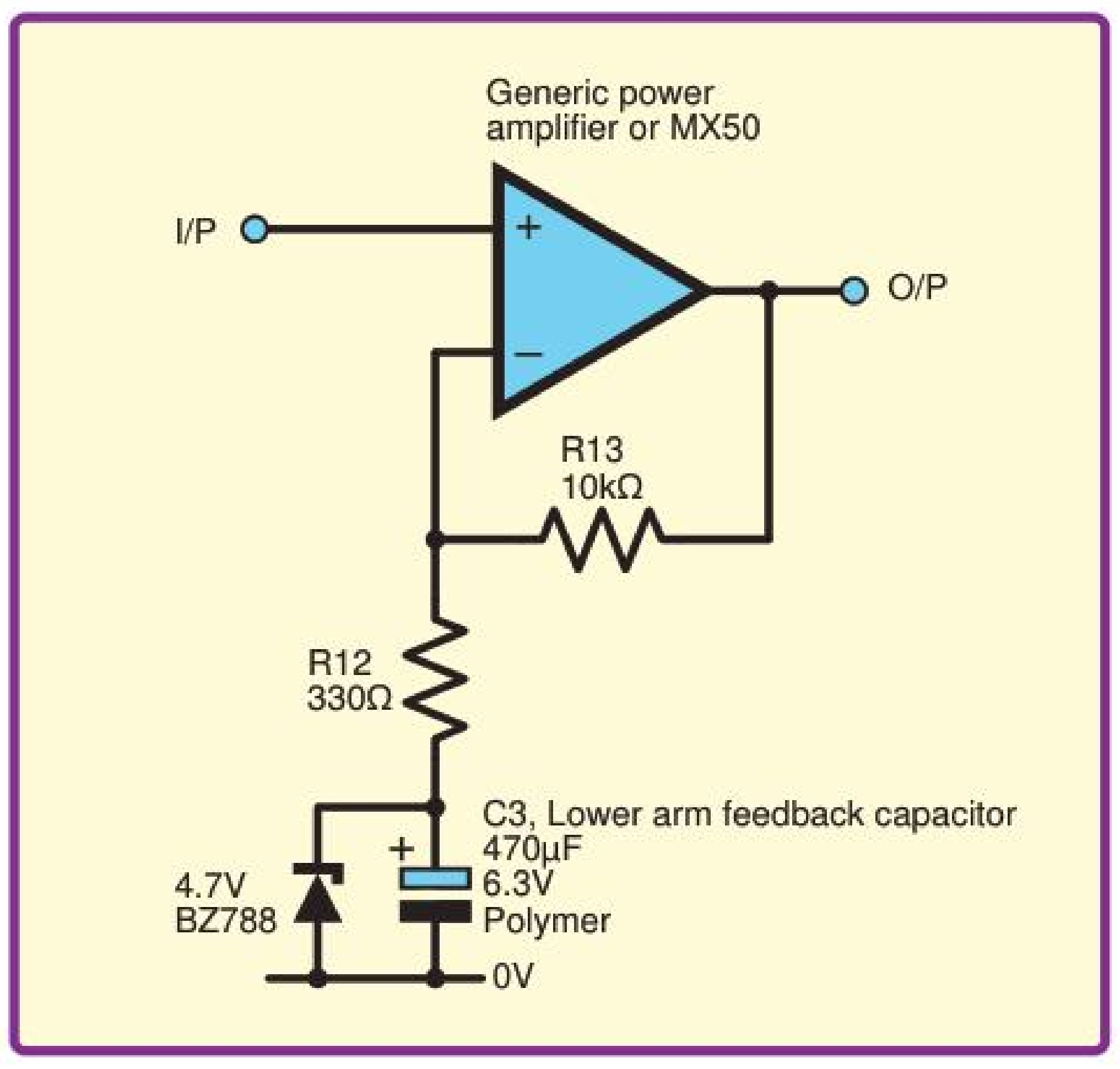

Fig.8. A Zener diode is needed to protect low-voltage polymer capacitors. Rapid sell a good selection of Würth polymer capacitors.

Decoupling capacitors

The decoupling capacitors (C8 and C9) can easily be replaced with polymer capacitors. These should improve stability, having lower ESR. High voltage ratings are rare, but they are available from Mouser. I used a 27μF 63V Nichicon capacitor – type PLV1J270MDL1TD.

If the negative rail is lost on the MX50, as well as the output going to full rail, I found all the capacitors on the negative rail also became reverse polarised. It is always worth checking for this if power rails are lost in any circuit. A solution is to include reverse-biased diodes from each rail to ground. D3 (see next month's column) added across the negative rail to ground gave an offset of 3V when the negative rail fuse was removed. Remember, fuses do fail randomly – suffering oxidation, and musicians like pulling fuses out and inserting Kit-Kat foil!

Next month, we will conclude this exercise in eliminating 'wet capacitors with a look at capacitance multipliers, gain reduction and tips on testing power amplifers.

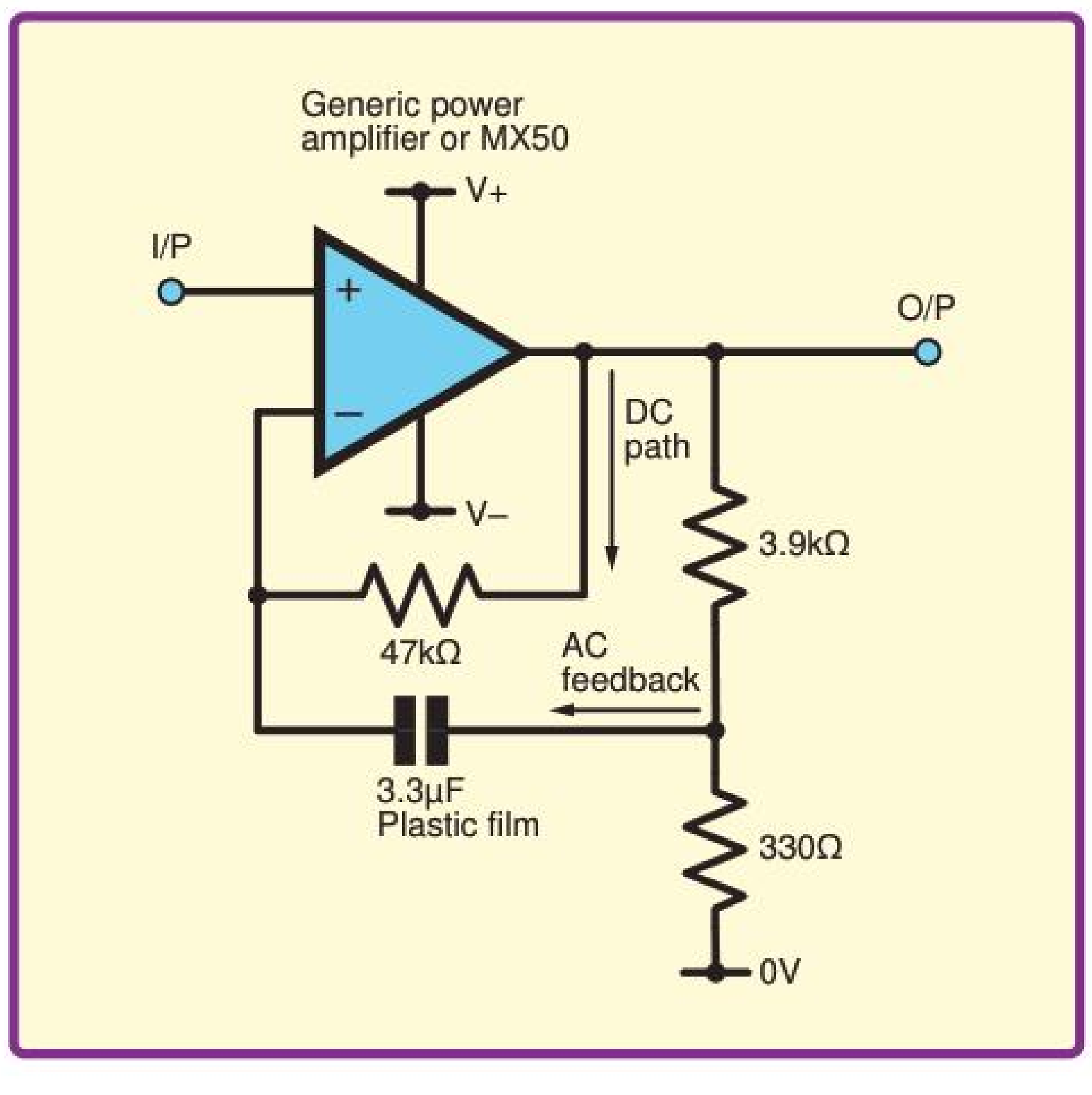

Fig.9. A new trick to get rid of the need for a high-value feedback capacitor. Note, to derive the gain the 3.9kΩ feedback resistor must be put in parallel with the 47kΩ resistor, giving R_f = 3.6kΩ.

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Max's Hot Beans

By Max The Magnificent

Oooh, shiny!

On the one hand, I like bright, shiny, modern technological products. On the other hand, I'm enamored of the technologies of yesteryear. I'm constantly discovering cunning creations from the 1940s, 50s, and 60s that leave me shaking my head in surprise and fill me with admiration for the ingenuity of their creators.

We've talked about different display technologies before. As you may recall, I like to repurpose antique analogue meters for appropriate projects (See *Max's Cool Beans*, *EPE*, January, February, March, and May 2015). If I wish to display information digitally, then one technology that really adds a certain *je ne sais quoi* to any project is Nixie Tubes (see *Max's Cool Beans*, *EPE*, April 2016).

One issue with Nixie Tubes is that they require ~170V to perform their magic. Another concern is that they are prone to esoteric problems like cathode poisoning. It's also fair to say that these little beauties aren't cheap; the cost of the big ones can bring tears to your eyes. Then there's the fact that they can be hard to track down. Until recently, I was convinced that the only remaining source was so-called 'New Old Stock' created in the 1950s and 60s in Eastern Europe and the USSR. Then I ran across Dalibor Farny in the Czech Republic, who lovingly hand-crafts the biggest and best Nixie tubes (**http://bit.ly/1PDJmRm** and see Fig.1). In fact, Dalibor custom built a set of Steampunk tubes (bronze bases and copper anodes) for my ongoing Nixie tube clock project, but that's a story for another day.

I've just read an article about the first digital voltmeter (DVM) produced by a company called Non-Linear Systems (NLS) in 1953 (**http://bit.ly/2grHHFV**). This little rascal employed a new type of display based on thin slices of Lucite, one for each digit, 0 to 9. Each slice was etched with its numeral and illuminated by a tiny incandescent bulb located on one edge. When one of the bulbs was activated, its associated slice of Lucite acted as a 'light pipe.' Wherever the light struck the engraved character, it was scattered, thereby allowing the operator to see the engraved numeral light up.

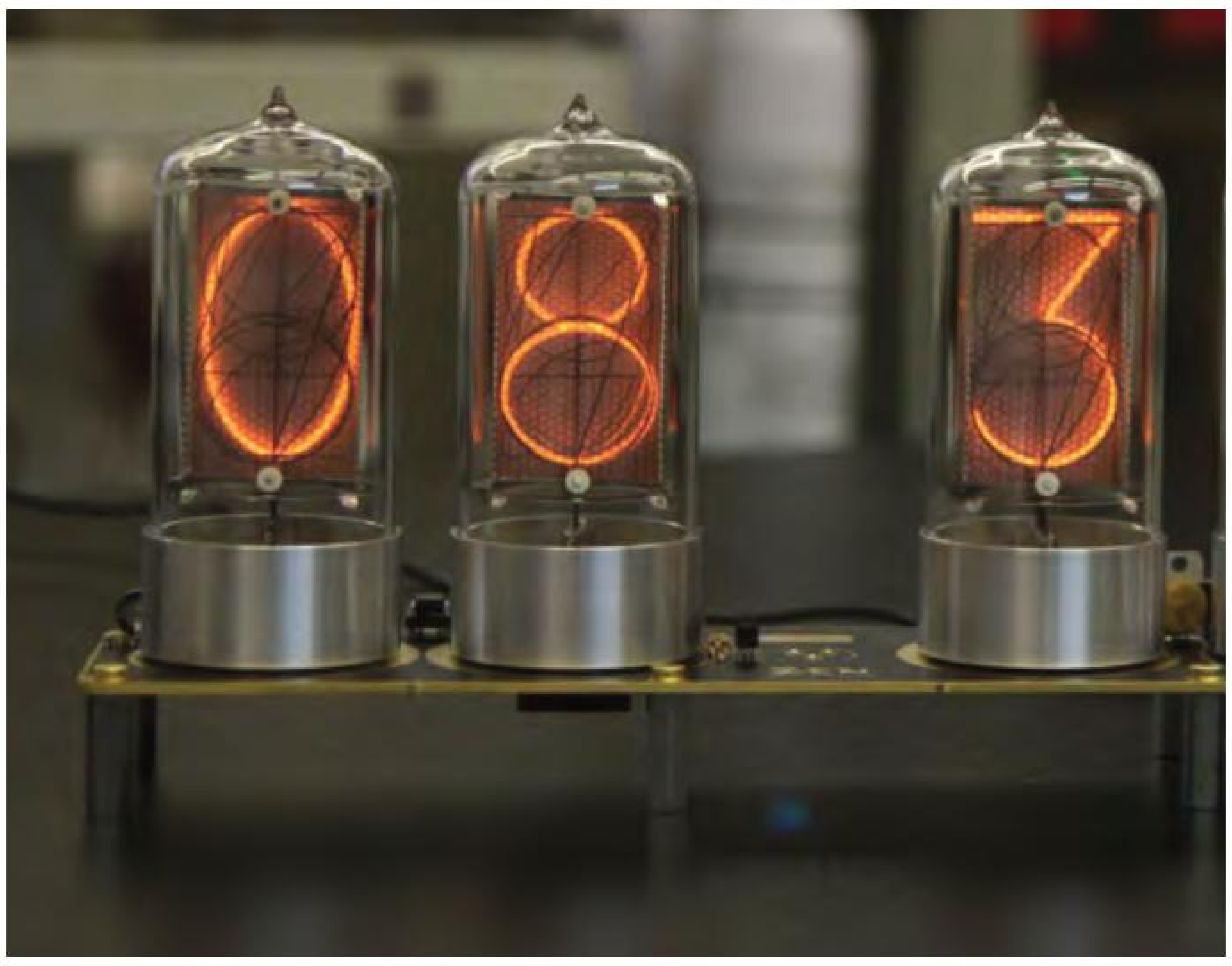


Fig.1. Gorgeous Nixie tubes from Dalibor Farny in the Czech Republic

LEDs and light pipes

The reason I mention this here is that I've recently run into two LED-based modern incarnations of this technology. The first is a UK creation called a 'Nixie Pipe' by John Whittington (**http://bit.ly/2eI4wkQ**). In this case, John laser-engraves a series of dimples (or holes, it's hard to tell) in thin acrylic sheets, where these dimples form the outlines of the numerals.

The second is a US implementation called a 'Lixie' by Connor Nishijima (**http://bit.ly/2mwQ3tc**). In this case, Connor laser-etches lines in his thin acrylic sheets. I was chatting with Connor just the other day, and he told me that his original prototype involved single lines, but he evolved to using an uber-cool two-line representation (Fig.2.)

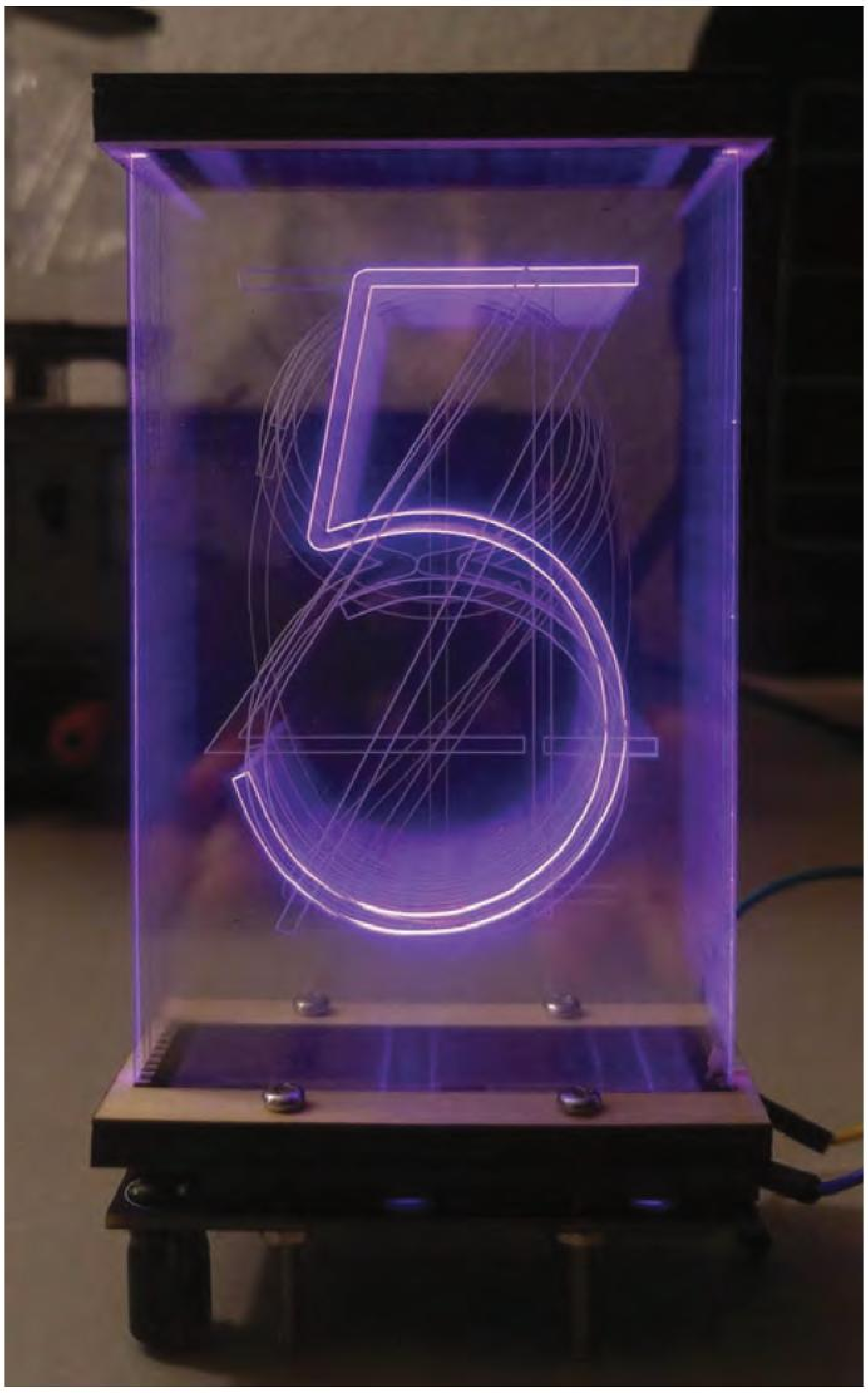


Fig.2. An LED-based Lixie display (Source: Connor Nishijima)

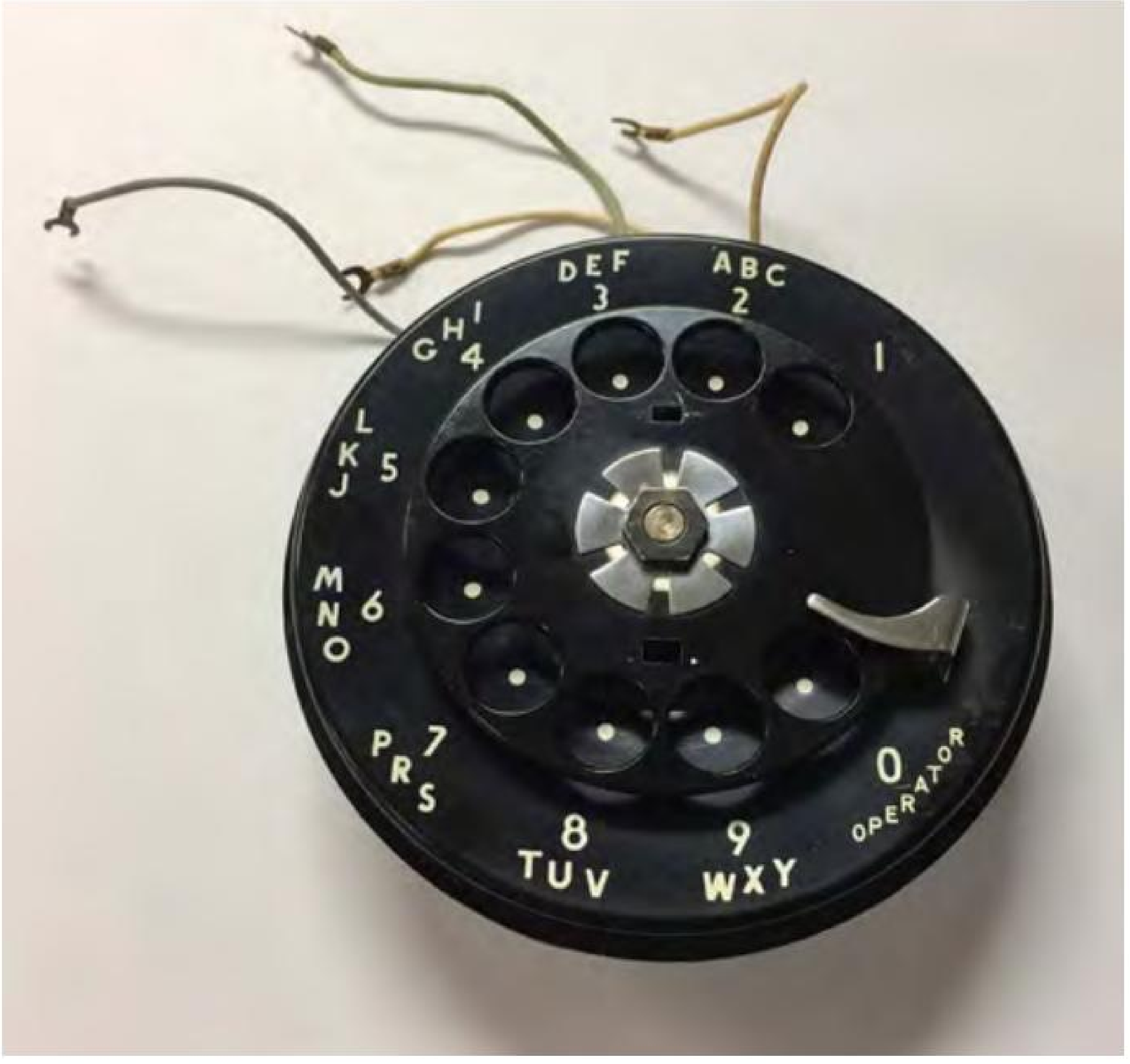


Fig.3. My latest acquisition

I love these displays, not least because they are relatively large (the acrylic sheets are 2.5-inch wide and 3.75-inch tall). I also love the font, which reminds me of my Nixie tubes. It turns out that Connor dismantled a broken Nixie tube, scanned its wire cathodes, and then scaled them up. I find the result very pleasing to the eye.

The circuit board at the bottom carries 20 WS2812 tri-color LEDs – two per acrylic sheet/numeral. These are the same devices that power Adafruit's NeoPixels (see *Max's Cool Beans*, *EPE*, July, August, and October 2015). This means that a Lixie can be driven using a single pin from an Arduino Uno, for example. Also, multiple Lixies can be daisy-chained together (they have 3-pin connectors on either side; 0V, 5V and Data-In on one side; 0V, 5V, and Data-Out on the other).

It's the final countdown

The great thing about Lixies is that they are open source; all the design files are available, allowing you to build them yourself. This was my original plan, but when I received my first Lixie from Connor and looked at the quality and workmanship, I decided that there was no point reinventing the wheel.

As soon as I powered up my Lixie, I was entranced. It's currently sitting on a desk outside my office counting from 0 to 9 and then starting all over again. If one Lixie is good, then more has to be better, but what should I use them for? I'm already working on a Nixie tube-based clock, so a Lixie equivalent would be a tad redundant. Also, Lixies are much cheaper than Nixies, which – of course – almost demands that we use more of them. (What can I say? I'm a weak man. I cannot help myself. Pity me.)

After mulling this over for a while, I decided to build a *Countdown Clock*. This is going to feature 12 Lixies, two each to represent years, months, days, hours, minutes, and seconds. I'm currently debating whether to present these in one long line of 12 digits or as two rows of six digits (in both cases, the digits would be arranged in pairs separated by spaces).

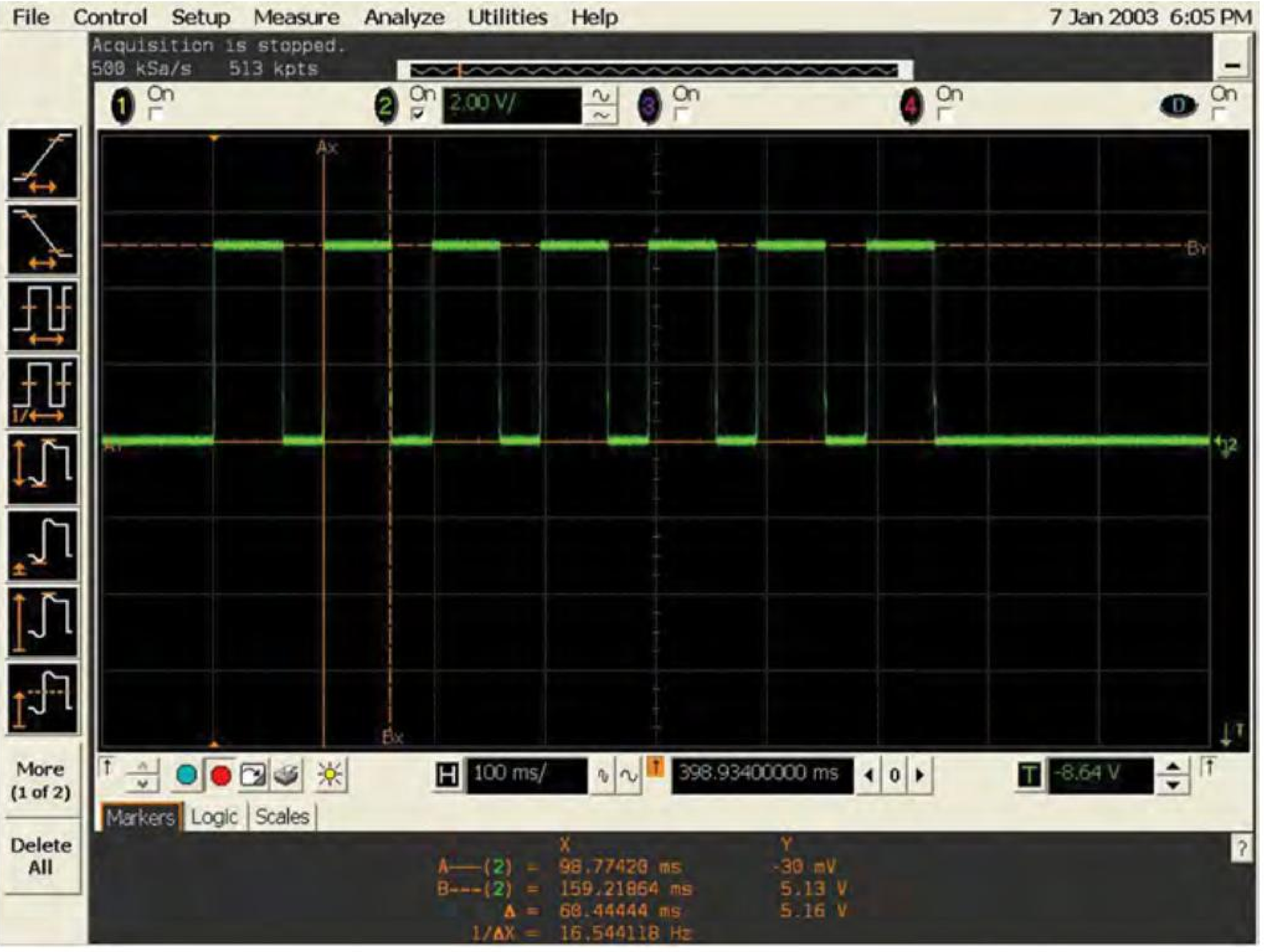
Now, if this device supported only a single event – say my 75th Birthday in 15 years, for example – then things would be a little boring (the most significant pair would change value only once a year). There are all sorts of effects I'm thinking of to make things more interesting, but a key element will be that the device will support multiple events and switch between them every couple of minutes. As part of this, we'll need to know the name of the event that's currently being represented.

My idea here is to have a large-ish (maybe 12-inch wide by 6-inch tall) LCD display, but make it look like a CRT (cathode ray tube). So, when we switch from one countdown event to another, the current text on the LCD will be erased, and then the new event description will be drawn as a series of lines and arcs. I'm envisaging emulating the way in which vector graphics might be drawn using an electron beam.

It's for you!

Suppose I wish to set an event for my 100th birthday, for example. This auspicious occasion will take place on 29 May 2057 (mark your calendars now so you can join in the worldwide celebrations). Let's say the festivities are to commence at 9:00am (I'm not going to get up early on my birthday). In this case, I will want to enter something like 57 05 29 09 00 00, for year, month, day, hour, minute, and second, respectively. As soon as I activate the 'Go Button' (or whatever), the system will use a real-time clock to determine how long there is to go; it will display the number of years, months, days, hours, minutes, and seconds remaining; and it will subsequently update the display every second.

So, an immediate question would be: 'How are we going to enter a target date into the countdown clock?' In fact, I'm planning on implementing multiple mechanisms, including the ability to add, delete, and modify entries via Bluetooth using my smartphone or iPad. However, this is all a bit 'so-so



```
Acquisition is stopped.
500 kSa/s    513 kpts
```

```
              X               Y
A——(2) =  98.77420 ms     -30 mV
B---(2) =  159.21864 ms    5.13 V
      Δ =  60.44444 ms     5.16 V
   1/ΔX =  16.544118 Hz
```

Fig.4. Testing the dialer mechanism

soup'. We also need to implement something that has a tad more bravura, panache, and gravitas, as it were.

When I was a kid, we had a single black telephone sitting on a small table in the hallway next to the front door in our house. This boasted a rotary dial with which you entered the number you wished to dial, one digit at a time (**http://bit.ly/1QYVsoZ**). You placed your index finger in the hole corresponding to the required digit and rotated the dial until your finger reached the end stop. When you removed your finger a spring returned the dial to its starting position while generating a series of pulses corresponding to the digit. (The reason I'm laboring this point is that I fear some of our younger readers may not have even seen one of these mechanisms!)

I love these things. The Western Electric model 500 telephone series was the standard domestic desk telephone set issued by the Bell System in North America from 1950 right up to the 1984 Bell System divestiture. I just took delivery of a really handsome restored Western Electric #7 Dial for 500 series telephones (Fig.3) from the Old Phone Shop (**http://bit.ly/2gtgTVV**).

This looks and feels fabulous. You have to see it to believe it. In fact, I just took a quick video of me trying the little scamp out (**http://bit.ly/2wlZP9E**). Now I'm kicking myself that I didn't use a couple of LEDs to show it in action (I'll be doing that as soon as I get home this evening).

As an aside, if you decide to do something like this yourself, be aware that different countries used different pulse mappings. In America, for example, one pulse corresponded to '1', two pulses to '2', and so forth, with 10 pulses corresponding to '0'. In Sweden, they used one pulse for '0' and two pulses for '1', up to ten pulses for '9'. New Zealand opted for ten pulses minus the number being dialed, so dialing '7' produced three pulses (and don't even ask me about Norway).

You will observe four wires in Fig.3. Two of these are connected to a switch that closes when you start dialing a number and opens when you've finished. The other two are connected to the switch that opens and closes to generate the pulses. So, the next thing I did was connect a 5V supply via a 10kΩ resistor to the terminals that generate the pulses and monitor things on my oscilloscope (Fig.4).

I dialed the number '7' and was delighted to see seven perfect positive pulses, each of which has a duration of approximately 100ms (60ms at 5V and 40ms at 0V). I'm amazed how regular these pulses are; also, that there's no perceptible overshoot or undershoot on the signal transitions. This is going to be a pleasure to work with.

There are so many ways in which we can use our dial to enter numbers. For example, flicking an 'Enter New Event' switch could cause all of the digits to display '0' characters in a dull red glow, with the most-significant (left-hand) digit pulsing slightly. When we dial the first number, it could appear in white on its Lixie, then the next digit could start to pulse, and so forth.

I'm now looking forward to a happy few days experimenting with different ways of entering and displaying data using my rotary dialer in conjunction with my Arduino and Lixies. I will report further in future columns. Until then, have a good one!

Any comments or questions? – please feel free to send me an email at: **max@CliveMaxfield.com**

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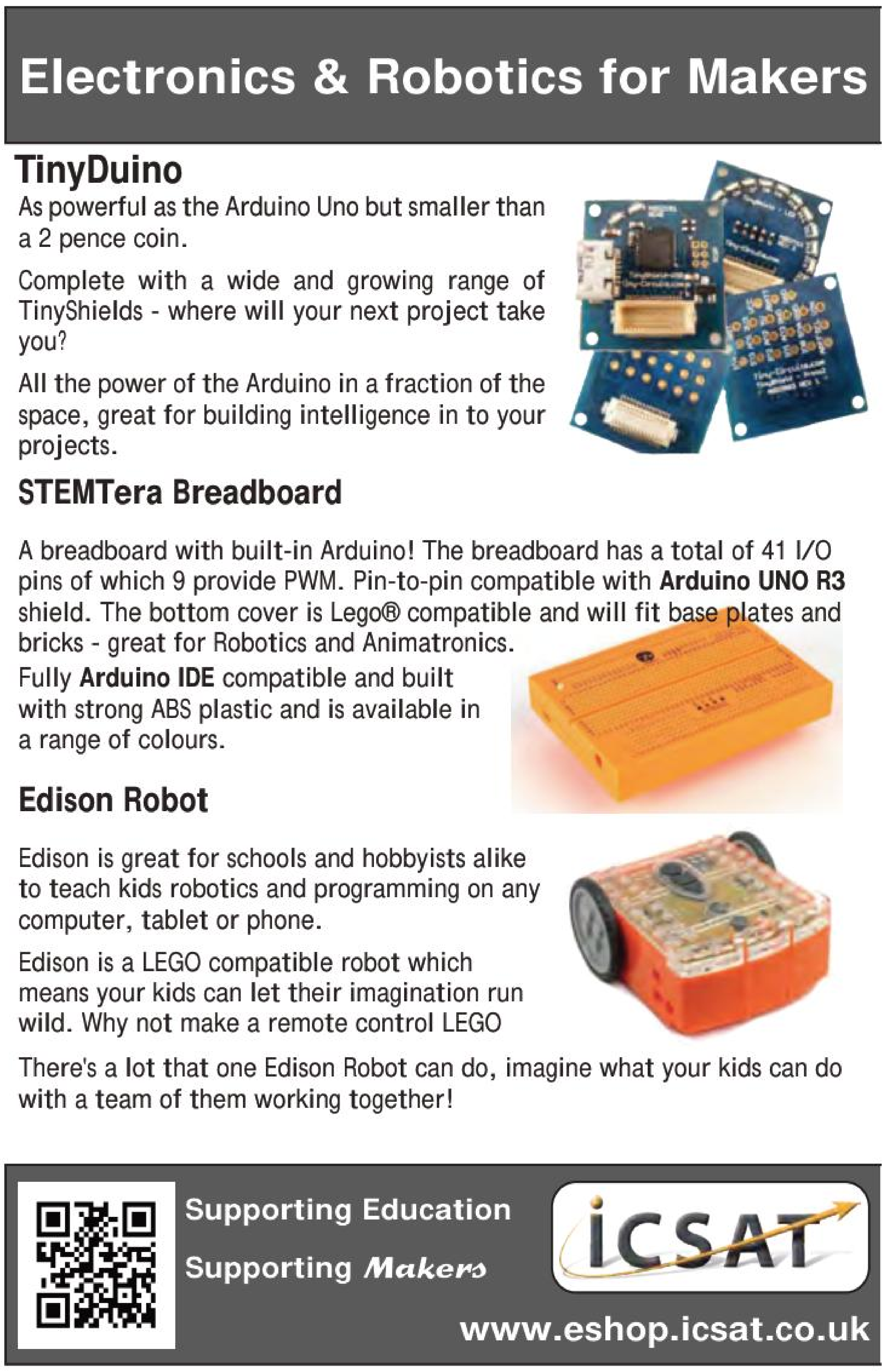

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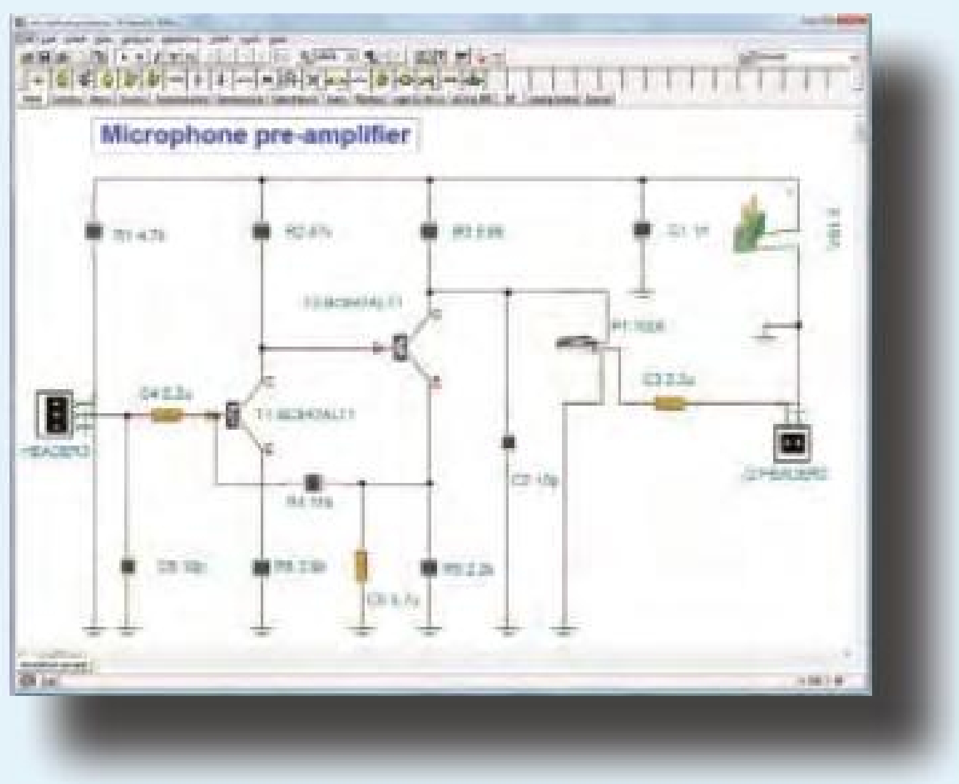

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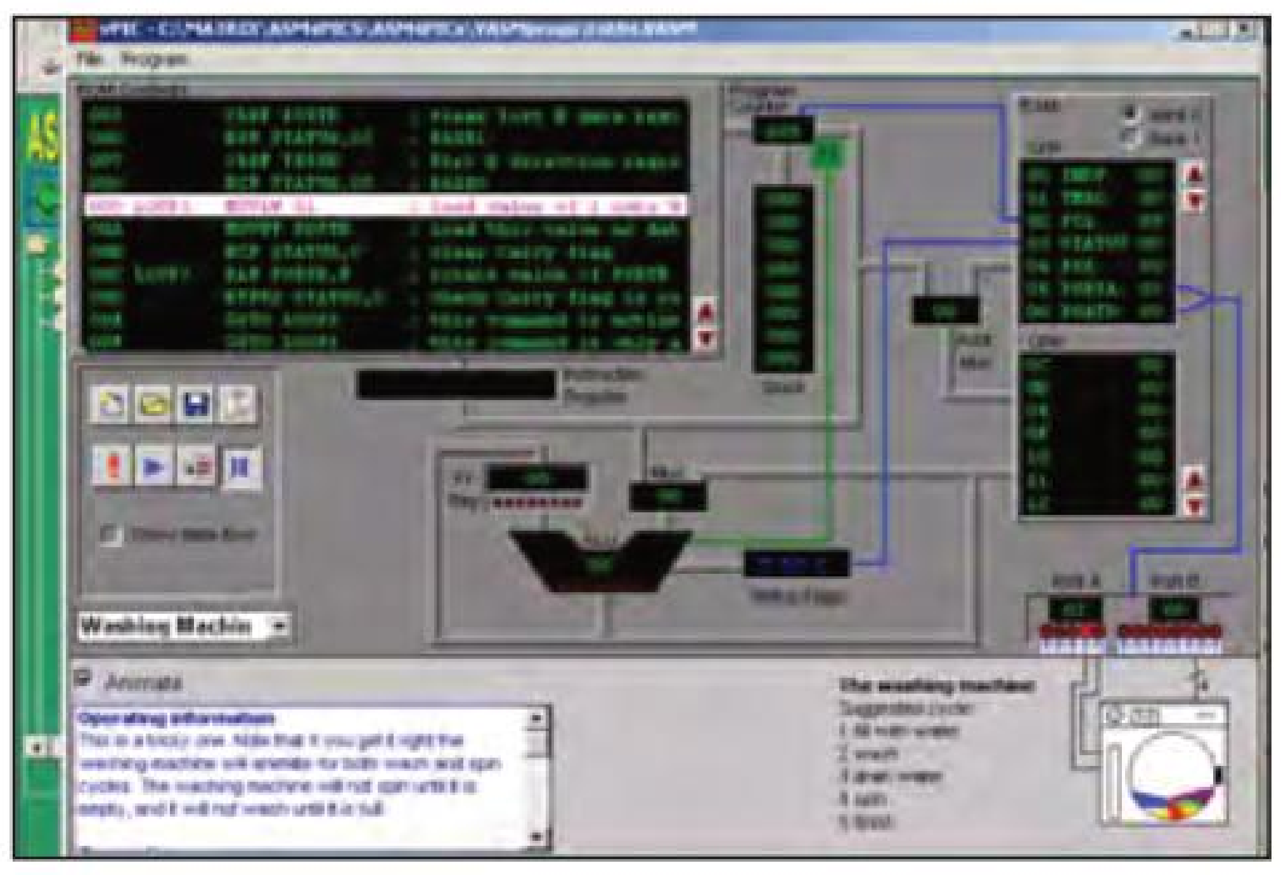

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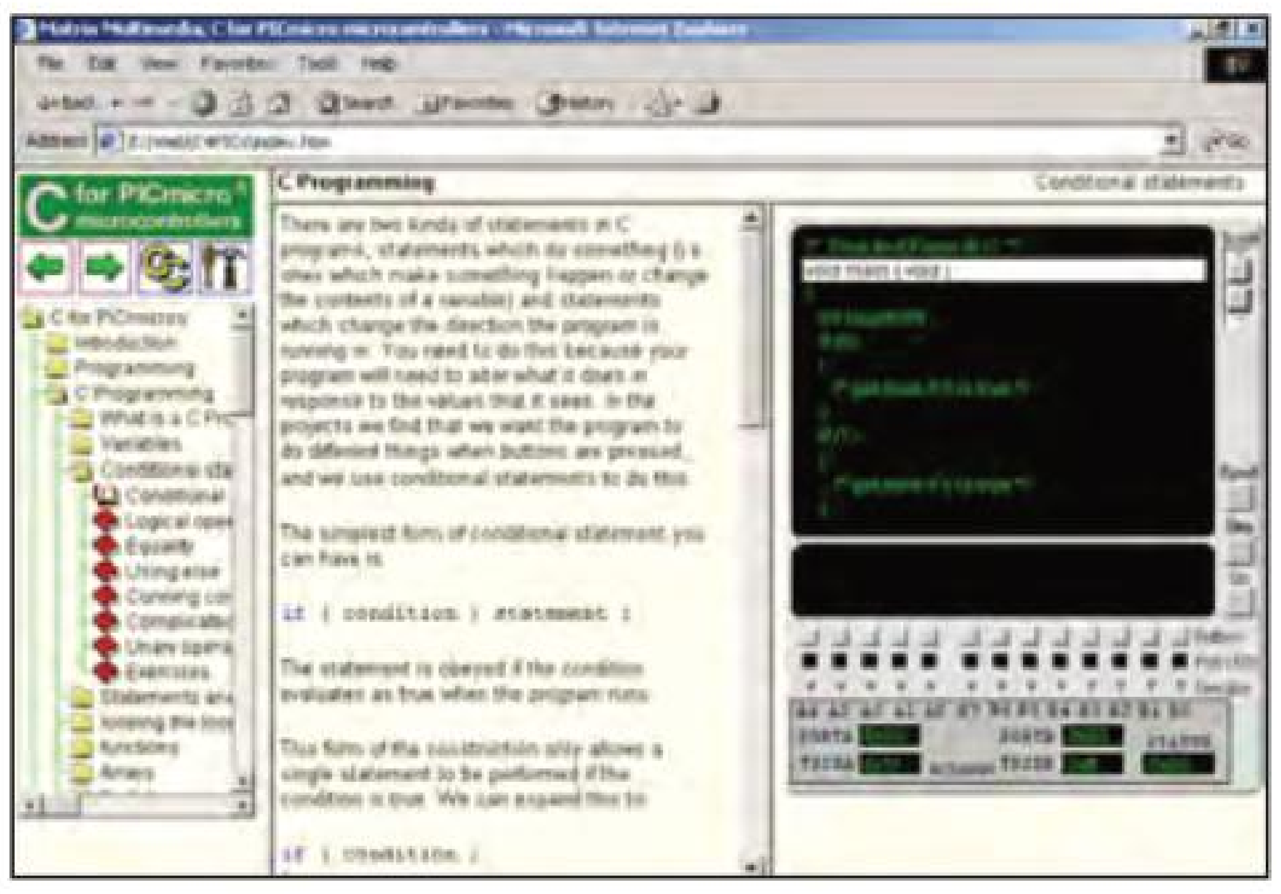

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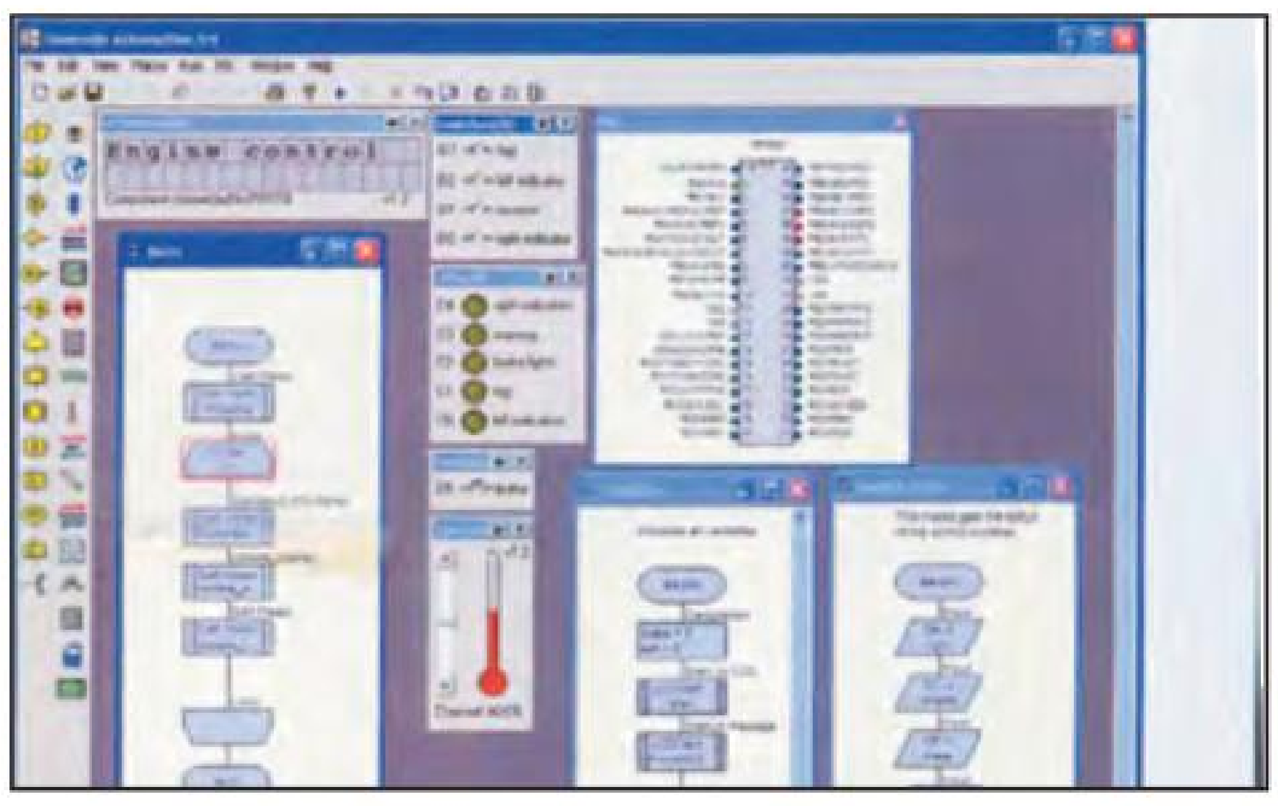

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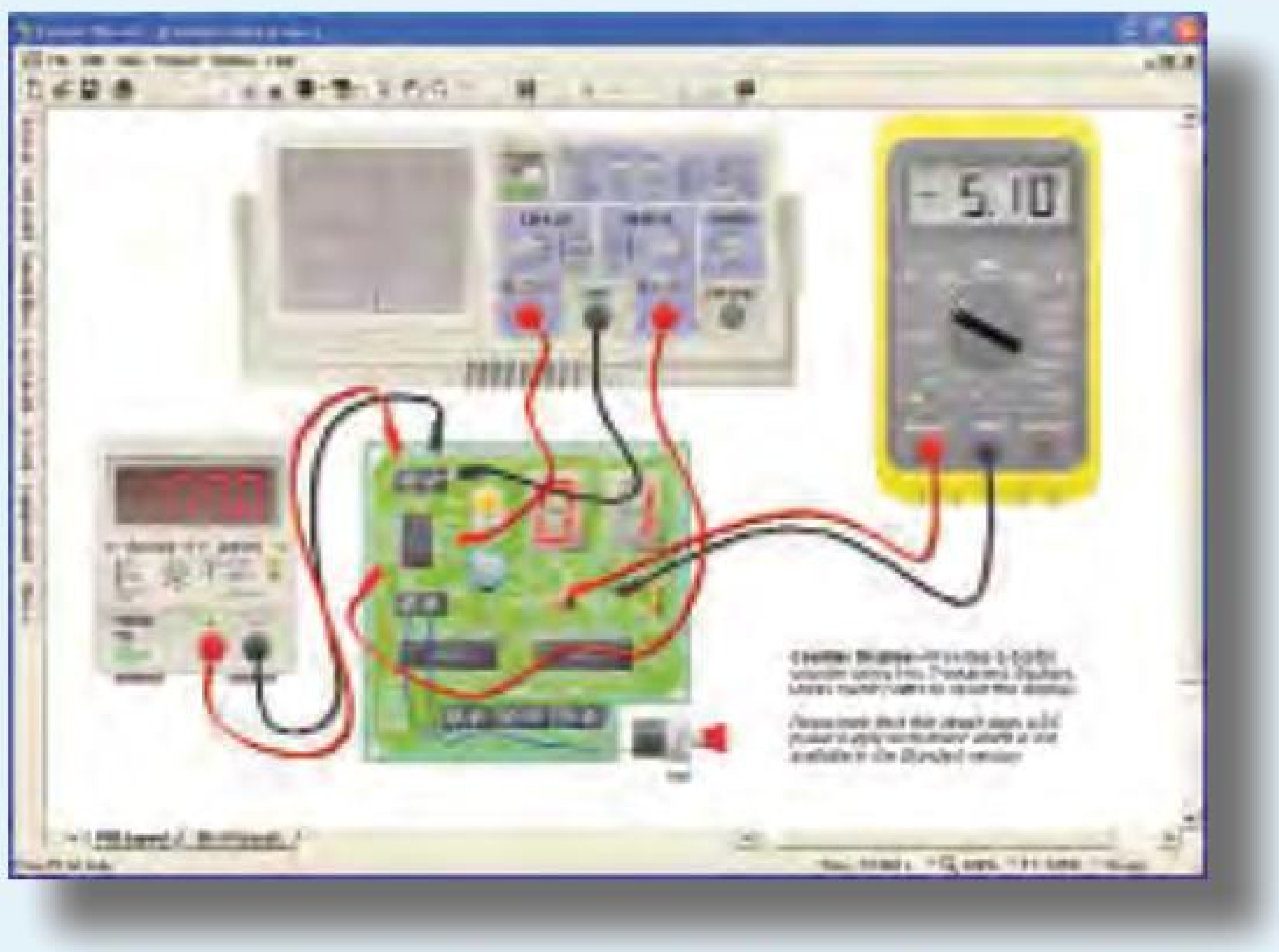

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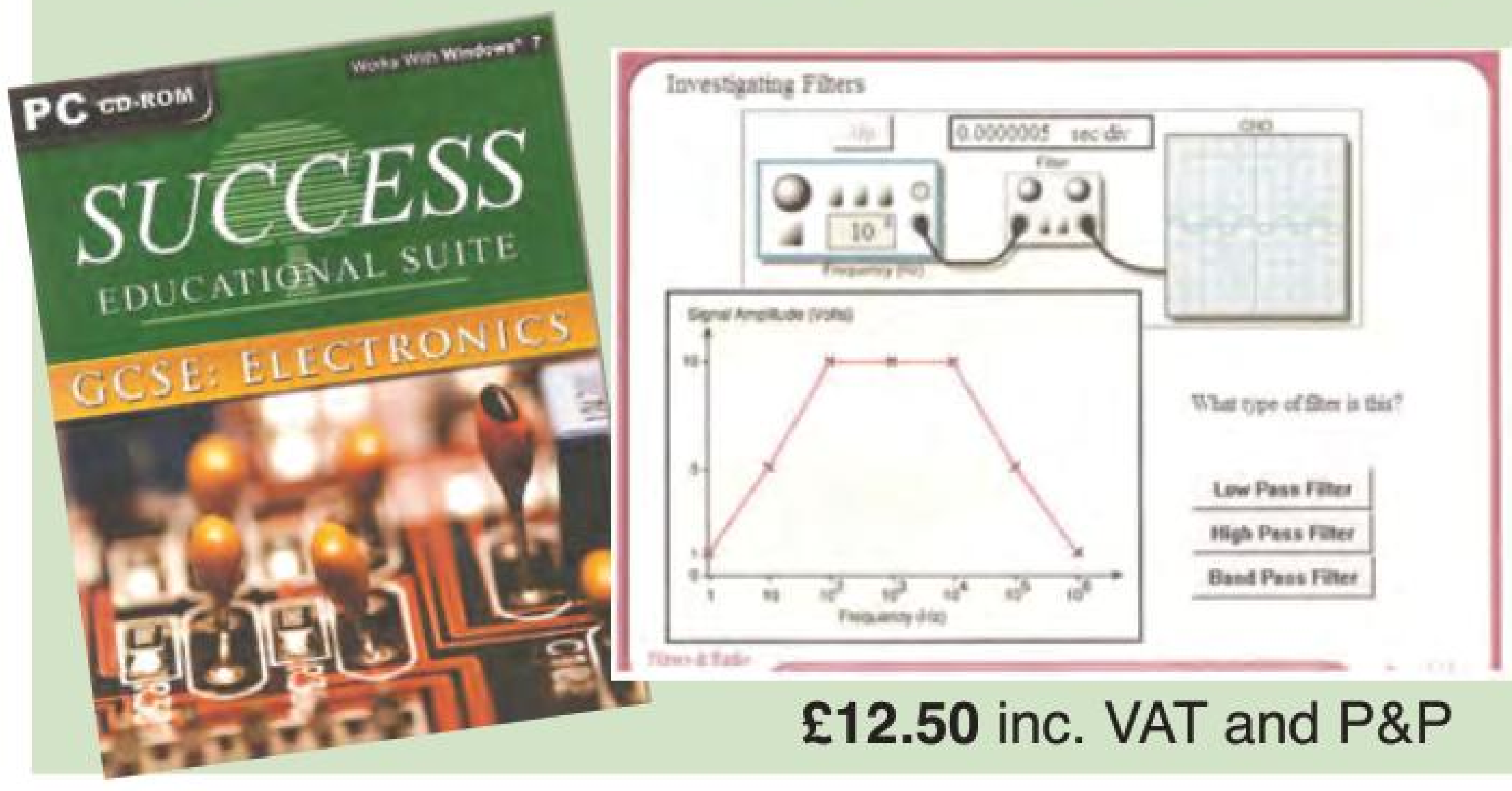

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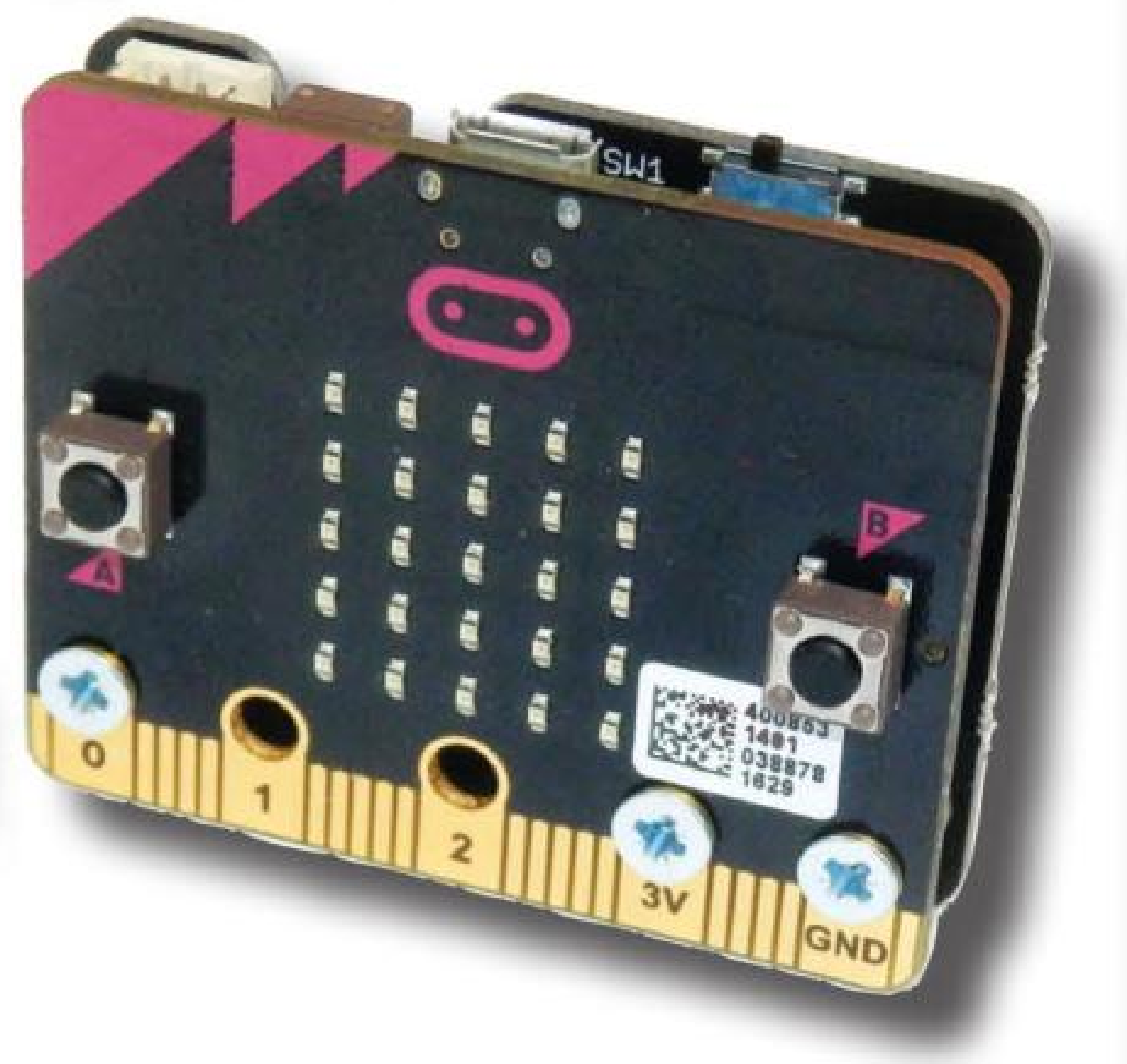

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Mike Tooley

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Mike Tooley

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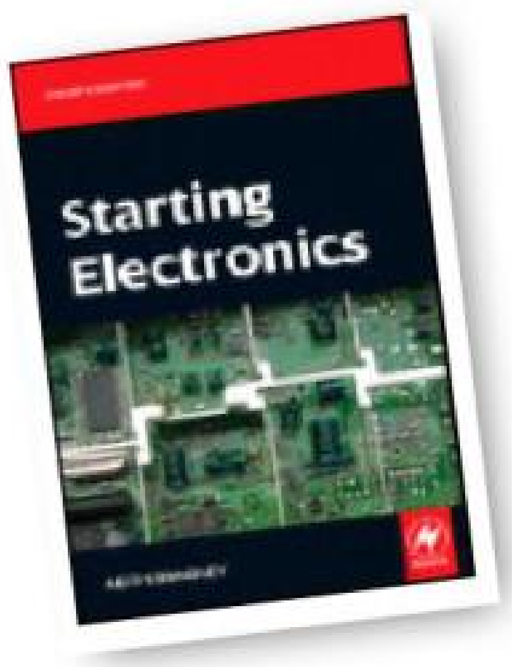

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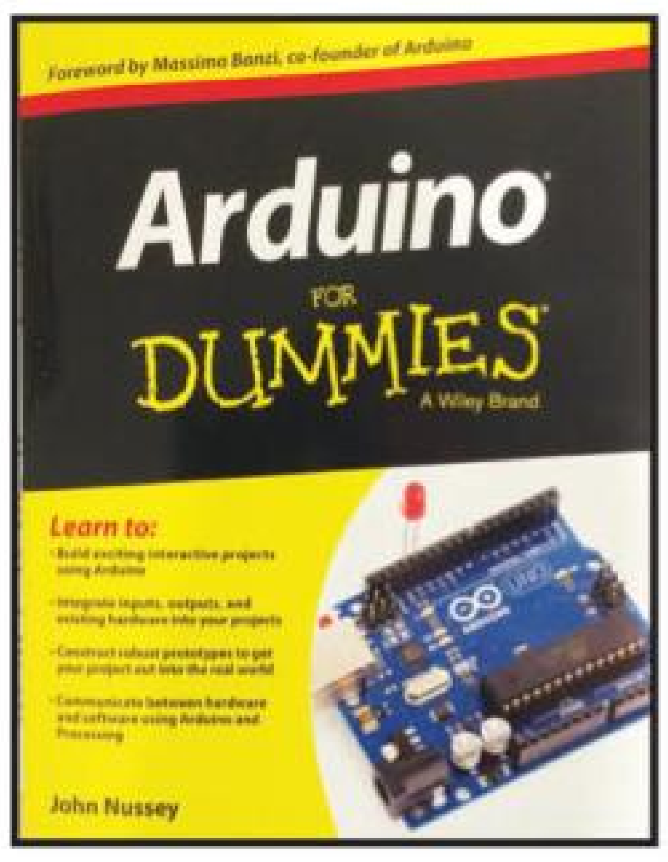
Teach-In 2016

Exploring the Arduino



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John Nussey

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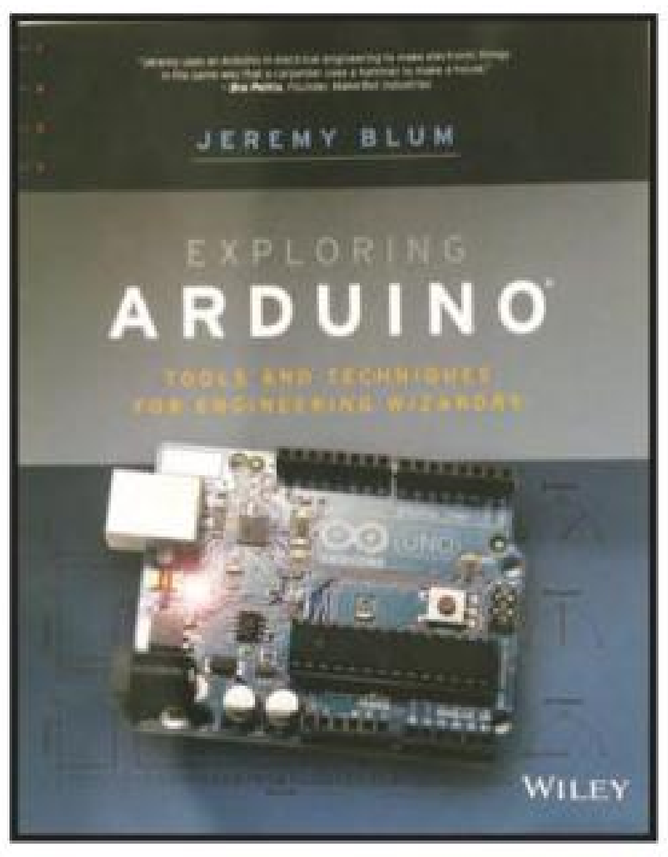

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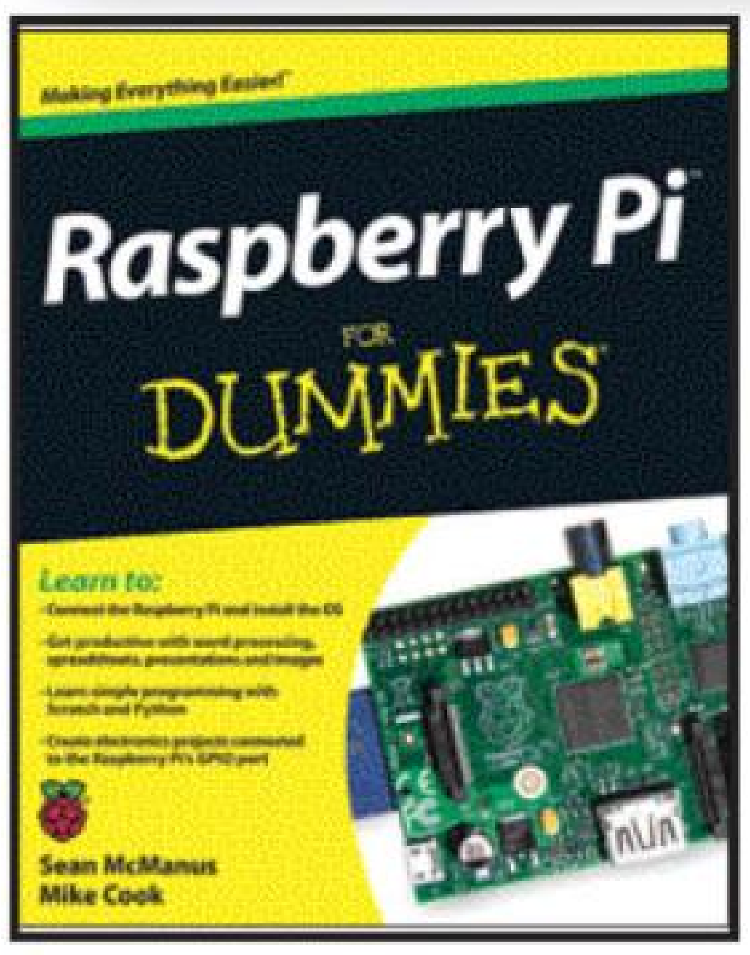

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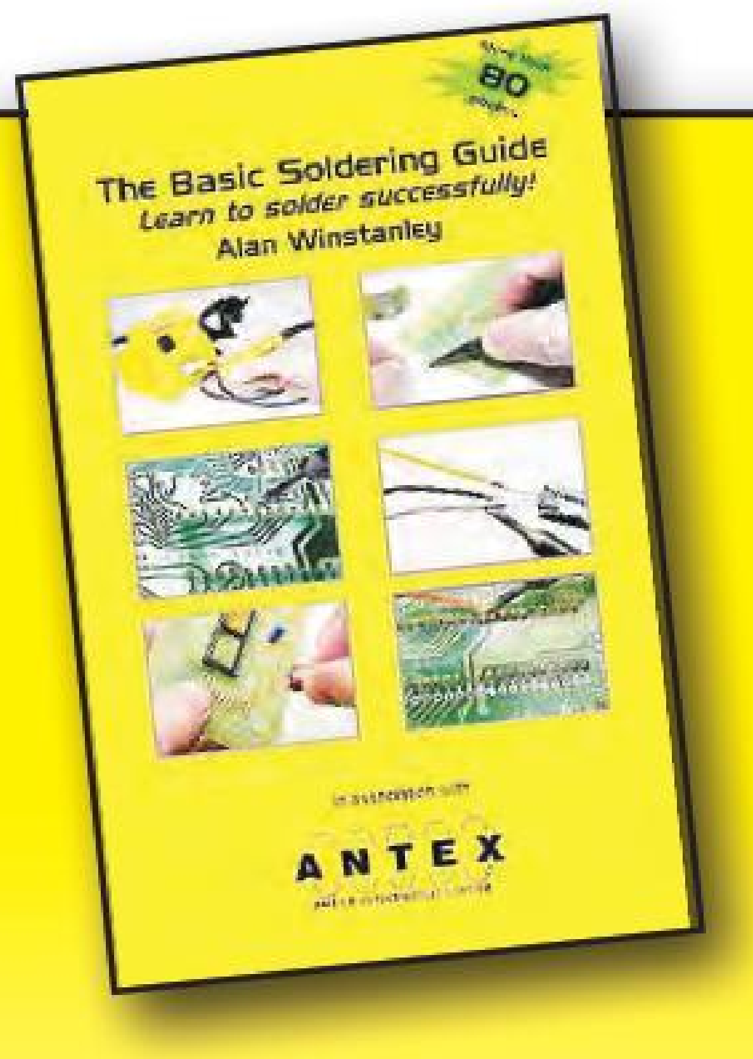

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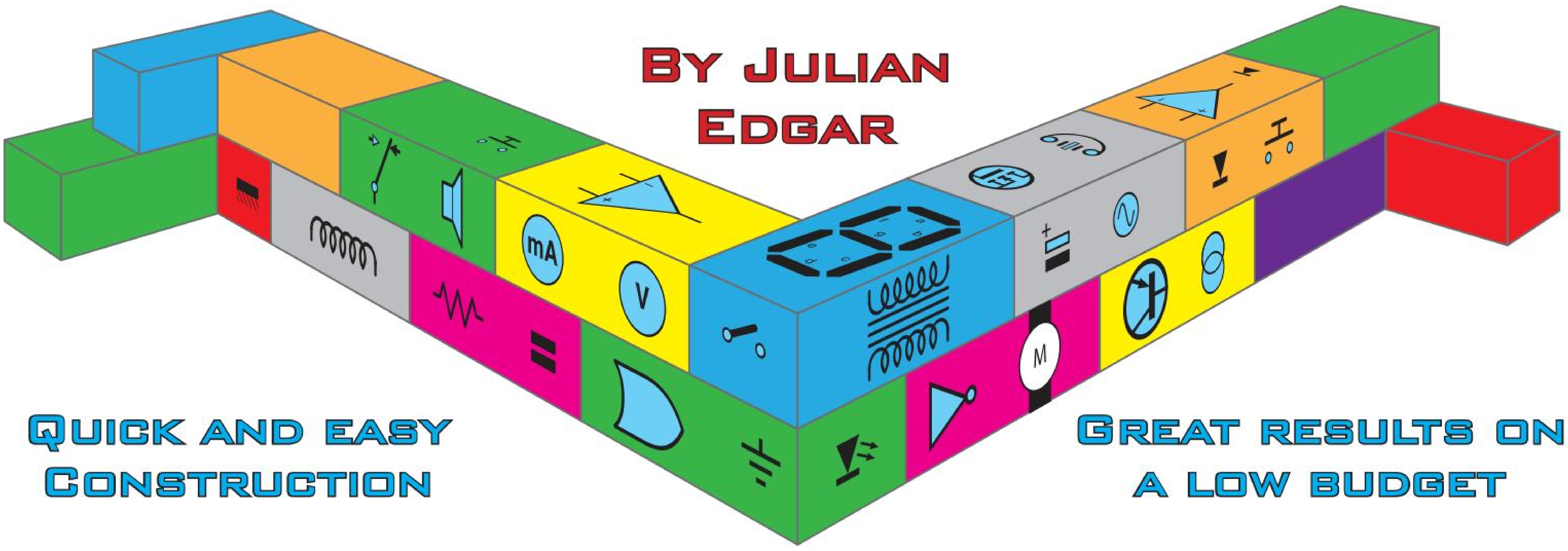
Electronic Building Blocks

By Julian Edgar



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High-current battery charger

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Here's a 'blunt instrument' with plenty of grunt that costs very little but can be extremely useful. So what is it? It's a *High-current Battery Charger* that's perfect for quickly bringing a car battery up to a level that will allow it to start a car, or for quickly recharging a home-built electric go-kart or similar. It will also charge 24V truck batteries.

The good news is that it can charge continuously at 35 amps, and for short term use can crank out an amazing 100A. (But more on current ratings in a moment.) *The bad news is that this is NOT the sort of charger to leave unattended – as presented here, control is completely manual.*

Starting points

This project began when I was at the local rubbish tip with my 12-year-old son. Eagle-eyed Alexander spotted an old arc ('stick') welder, missing its welding leads and a bit rusty, but otherwise looking fine. It was a compact, fan-cooled design that used a small knob on the front face to adjust welding current. It was unwanted and discarded – so we took it home.

Testing it showed that it worked fine – but I already have some very good welders, so it was no use to me as a welder. I opened it up to find a huge transformer and an electronic module controlled by the knob. The module, presumably using a silicon-controlled rectifier (SCR), varied the input voltage to the transformer's primary.

I was thinking of making the welder into a battery charger, but the variation in output voltage achieved by the knob was too small. In the past, that would have stopped the project, but these days, high-power adjustable SCR modules are readily available. In fact, available from **www.banggood.com** is a 10,000W (yes, 10kW!) adjustable SCR unit for just under £10, post included. (Product ID: 1068387.) Similar units are also available on eBay.

I ordered one and when it arrived, I removed the standard adjustment module from the welder and replaced it with the new one. I could then adjust output voltage from 0 to 50V or 75V, depending on which of the two transformer output tappings I used.

(Incidentally, the high current output sockets on the welder were also a bit tired, and so I replaced these with new ones – £2.30 from Banggood, Product ID: 934469. I used some salvaged jumper leads to make my battery connections.)

At this point, I had a bit of fun. I wound some thin steel wire around a broom handle until I had formed a long, high current resistor. I removed the wire from the handle and carefully mounted it in free air. I then ran heavy cables from each end of the wire coil to the output terminals of the welder (now an adjustable AC power supply) and then gradually wound up the knob. It was quite easy to have the 'resistor' wiring glowing bright red – most satisfying.

The next step was to rectify the AC output. I already had a three-phase high-current rectifier (salvaged in the past from other equipment) but

WARNING!

This is a project that involves high voltages. Do not tackle a project of this sort if you are unfamiliar with appropriate safety precautions for AC mains voltages and DC voltages up to 75V or more.

Here's the welder-battery charger pushing over 42A into a large car battery.

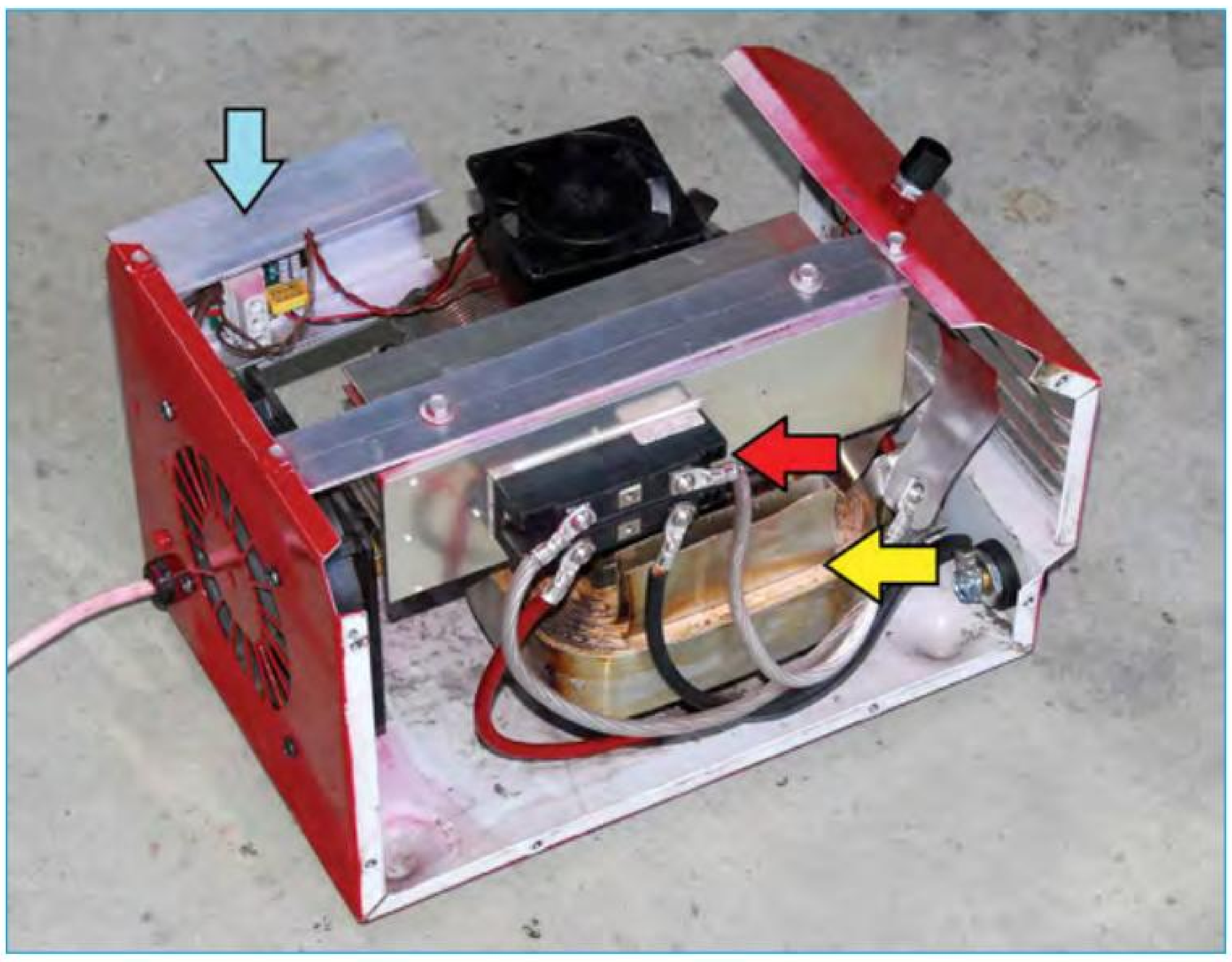
Making possible the conversion of a welder into a high current battery charger is this 10kW SCR module that costs under £10. It's used to adjust the primary transformer current.

100A rectifiers are available on eBay from about £8 (post included). Buy a rectifier that has proper screw terminals, rather than spade connections – you need the connections to have a high-current capability. These rectifiers need a large heat sink, which can be bought new or salvaged from other goods (eg, an old audio amplifier).

Building it

The actual steps you take in building the high-current charger depend on the design of the welder that you're starting with. So here are just some key tips:

- The new SCR module should be earthed to the metal case of the welder, and the welder case should in turn be earthed through the mains plug. You may need to add a new cable to the SCR heat sink / case for this earthing function. The wires that attach to the adjustment pot can be extended as required to allow you to mount the pot on the front of the charger.
- The high-current connections within the welder (eg, to the output terminals and bridge rectifier) need to be made with heavy-duty cable, for example cable with a copper diameter of 5mm (20mm^2). The connections should be via crimped or soldered heavy-duty copper lugs. (If you don't have this sort of crimper, a local automotive electrician can do this crimping for you at nominal charge.) This cable is available by the metre from automotive electricians and also those shops installing high power car sound systems. You cannot use thin cable for these connections!
- The transformer, bridge rectifier heat sink and SCR module heat sink all need plenty of fan-forced air cooling. To be honest, I was surprised how hot everything got without carefully designed, very powerful airflow. If the welder is not already fan-cooled, you will need to add one or two strong fans and cut appropriate vents to allow this air movement. It is easiest if these fans are mains-powered. In my charger at least, the item needing the greatest heat sinking was the rectifier.
- I use a clamp-on ammeter and my multimeter to measure current and voltage, but you can easily add panel meters to do this. So that there is no need to add a low-voltage supply, use analogue meters. A 50A ammeter (complete with shunt) is available on eBay for around £5 (search under 'New DC 0-50A Analog Amp Meter Ammeter Current Panel + Shunt Resistor') and similar style 0-20V ammeters are only a few pounds (search under 'DC 0~20V 85C1-V Class 2.5 Voltmeter Analog Volt Panel Meter').



An inside view – the yellow arrow points to the enormous transformer that originally provided the welder's secondary current; the red arrow points to the new rectifying diode block mounted on a large heat sink; and the blue arrow shows the new SCR module that allows charging current to be adjusted. The fan near the top of the picture attaches to the cover.

Current

So how much current can this charger output? First, the current is controlled by simply turning the knob. In the one I built, and charging a large 12V lead-acid car battery, the charger could develop a measured 50A at 17V. But is this sustainable?

Welders are always rated on their *intermittent* output. For example, the welder I have used is stated to be a '140A' type. However, closer inspection of the specs shows that this is at only 18% duty cycle (that is, on full load for about 11 seconds every minute). It is also rated at 98A – but at 25% duty cycle. This might imply that the unit can run continuously at around 25A – but that also depends on how much cooling air you can pass through the box!

In short, the higher the stated current capability of the welder, the better, but in a battery charger application you need to divide that number by typically four or so to gain an approximation of the continuous current capability. The charger shown here, equipped with a second fan, can run at a continuous 35A.

Using it

To emphasise what was stated earlier – this is not a charger to connect and forget! During charging, the current and the battery voltage will vary over time. You should adjust the knob so that, with a very flat battery, current doesn't exceed your designated maximum (eg, 35A for mine), and then, as the battery voltage rises, adjust the knob so that the battery is not over-charged.

That might seem tedious (and of course you could easily develop a more sophisticated control system) but in actual use, the knob needs to be adjusted only occasionally. Plus, with this much current available, the charging period is usually fairly short!

Finally, do ***not*** use the battery charger as a general-purpose DC power supply – the ripple on the output is horrendous!

Conclusion

If you can find an old transformer-based welder going cheap (or better still, free), it will take only about £25 to turn it into a very powerful charger suitable for car and truck batteries – a pretty good discount over the hundreds of pounds you'd otherwise pay.

Next time

In my next column I'll be looking at an *LED VU Meter* to add bling to your next amplifier design.

PCB SERVICE

CHECK US OUT ON THE WEB

Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.

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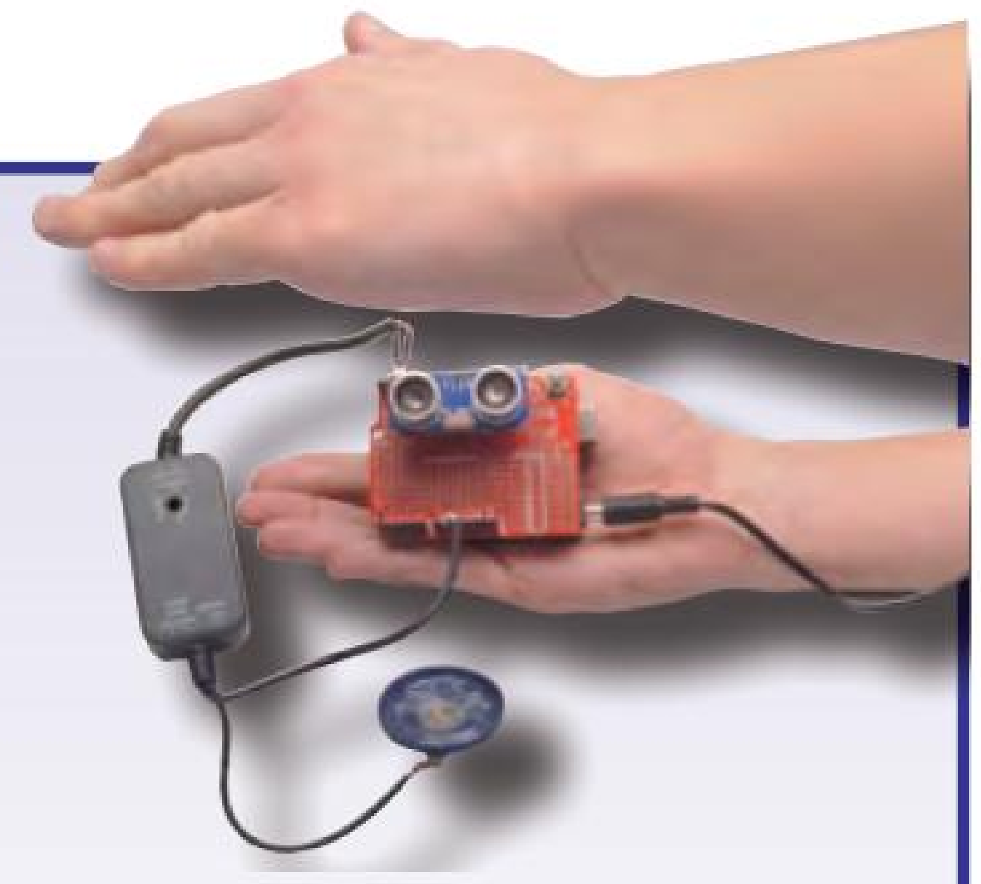


Digital Theremin using Arduino

EPE has described quite a number of Theremins over the years, but this is something new: an Arduino-based Theremin with hand sensing via an acoustic distance sensor.

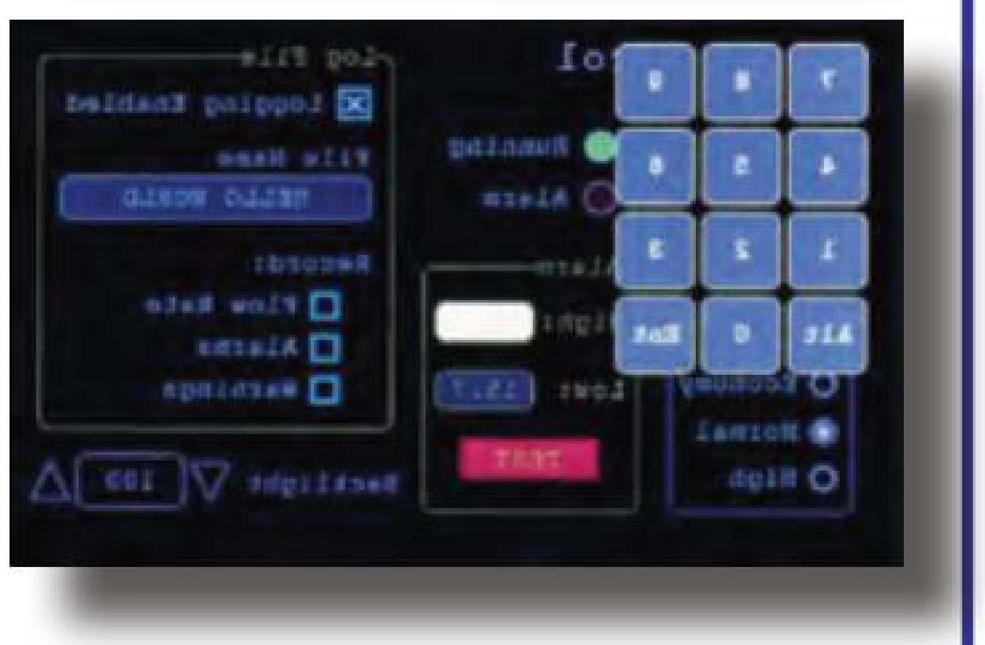
- 10.0mA+
10.0mA±.1%
Menu

Precision Voltage and Current Reference with Touchscreen Control – Part 2

We introduced this instrument with its comprehensive touchscreen control in the October issue. In this second and final article, we give the construction details and provide all the testing and operation instructions.

The Micromite Plus LCD BackPack

The Explore 64 and the Micromite LCD BackPack have had an illicit affair and here are the secret baby photos to prove it! It has its mother's eyes and father's brain. OK, that's not really true; what we have done is taken the best features of each project and put them together onto a single board.



Micromite Plus Advanced Programming – Part 2

Last month, we went over some of the new features of the Micromite Plus, including reading and writing files on an SD card and defining GUI controls. Now we're going to take a look at some extra features that allow even more advanced GUI controls to be built very easily.

Teach-In 2018 – Part 3

In next month's *Teach-in 2018* we will be looking at AC measurements and our practical project will feature a wide-band RMS voltage adapter that can be used to improve the AC performance of most digital multimeters

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All your favourite regular columns from *Audio Out* and *Circuit Surgery* to *PIC n' Mix* and *Net Work*.

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